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| Research Article

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Strengthening Methods of Reinforced Concrete Columns

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Abstract

In our project, we are talking about strengthening the columns in general. First, we began to search for the types of columns and all their general information and types of column failures such as (the increase in the number of floors and errors during design and implementation, as well as the poor quality of the materials used) and we also searched for the types of cracks that occur in the columns After that, we started looking for techniques that help to strengthen the columns and increase their bearing loads such as (concrete jacket, steel jacket and CFRP), then we talked about the working mechanism and the advantages and disadvantages of each. Finally, we took a design for a column and made the necessary calculations, then we increased the number of floors using the concrete jacket and the steel jacket, and then we made the calculations whether it could bear the extra weight or not.

Keywords: column، concrete ، steel ، load ، jacketing

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1-1 Introduction:

Enhancement of the reinforced concrete buildings is an important activity in the structural maintenance. Strengthening is meant to enhance the capacity of an already existing structural element. The reinforcement or retrofit of old reinforced concrete (RC) buildings must be strengthened or reinforced due to several reasons.In some cases it can be a change in use which results in increased loads, degradation through environmental effects or the lateral loading requirement. The column is a necessity in any structure. The strengthening is done to increase the compressive strength and ductility of the column. FRP confinement increases the final compressive strength of concrete and the ultimate compressive strain. The most widely used fabric of column jacketing are concrete (reinforcing bars or fiber-reinforced), steel, or fiber-reinforced polymers. Such materials are used extensively in the modern day strengthening of columns.

Column: Generally, a column is something which carries load from beam and slab. In other words, columns are defined as the members that carries load mainly in compression. columns carry bending moment as well, about one or both axes of the cross section.

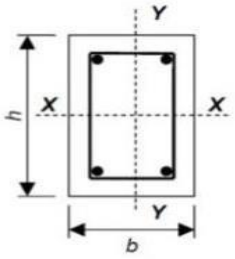


Figure (1-1) Column

1-2 Types of column:

1-By material:

- **Composite Column:** Composite column is a structural column that is made up of structural steel shapes or pipes, surrounded or full of the concrete, with or without longitudinal reinforcement as shown in the figure below.

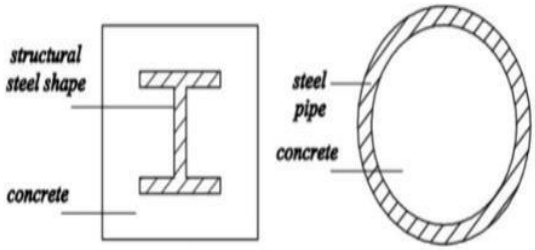


Figure (1 – 2) Composite column

- **Concrete Column:** A structural element that is exposed to compressive loads. Concrete columns can be un-reinforced, or reinforced with longitudinal bars and ties (tied columns), longitudinal bars and spiral steel (spiral-reinforced columns). It happens that sometimes such columns are composite, with concrete in practice mixed with structural steel or cast iron.

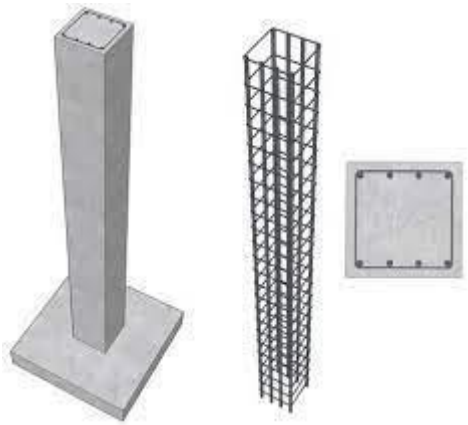


Figure (1 – 3) concrete column

- **Steel Columns:** are known to be strong in compressive strength but have the characteristics of buckling or bending under severe loads. Their total length and their main cross-sectional area are some of the causes

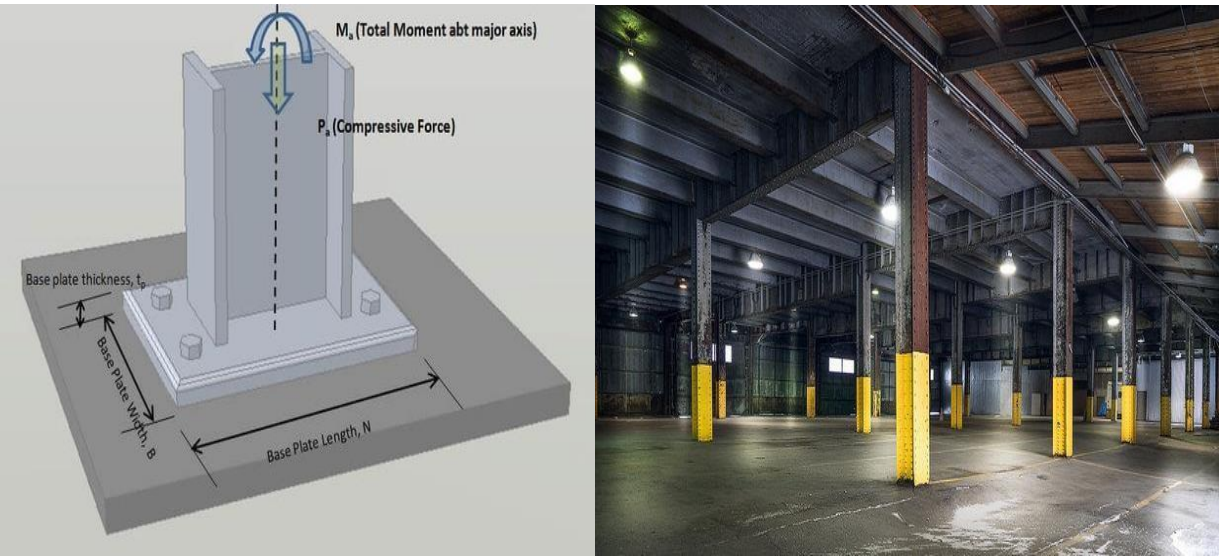


Figure (1 – 4) steel column

2-By shape:

- **Tied Column.** A tied column as shown in figure below is a column member whereby, longitudinal reinforcement bars are held together by transverse bars of smaller diameter (ties) spaced between them at an interval on the column height. These ties keep the longitudinal reinforcement stationary in an erecting process and provide stability of the bars against local buckling. The cross-sections of these columns are usually square, rectangular or circular. A minimum of four bars are used in cross-sections that are rectangular and circular.This description enhances confinement and ductility.

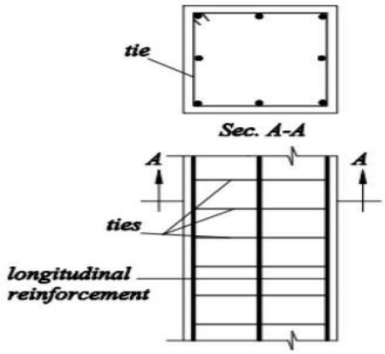


Figure (1 – 5) Tied Column

- **Spiral Column:** This type of column is where the longitudinal bars are positioned in a circle and enclosed by continuous spiral as depicted in figure below. These columns are circular or square.Longitudinal reinforcement is done with a minimum of six bars

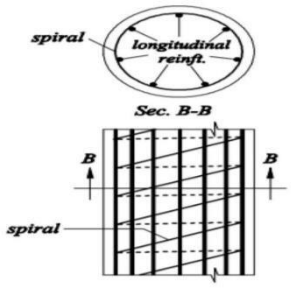


Figure (1 – 6) Spiral Column

3-By Cylinder his ratio:

Short Column: Short Column: A short column is a column with a ratio as less than or equal to 12 of effective length to its least lateral dimension. It is then respectively called a short structural column

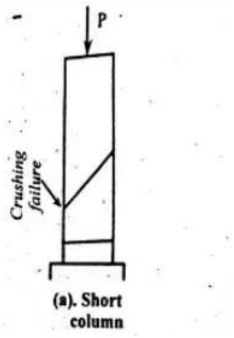


Figure (1-7) Short Column

- **Long Column**: a column is only so slender that it will not sustain longitudinal loading by crushing but only by bending, and is usually between twenty and thirty times the characteristic diameter of the member.

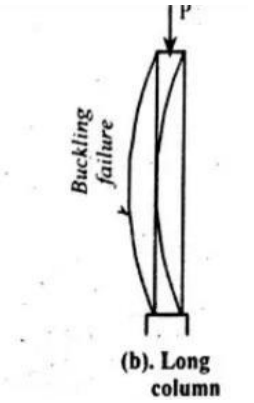


Figure (1-8) long Column

4-Type Column Loading: a-Axial

Load:

- **Axially Loaded Column:** Axially Loaded Column: An axially loaded column does not have a specific design to handle any other lateral loads or end moments.

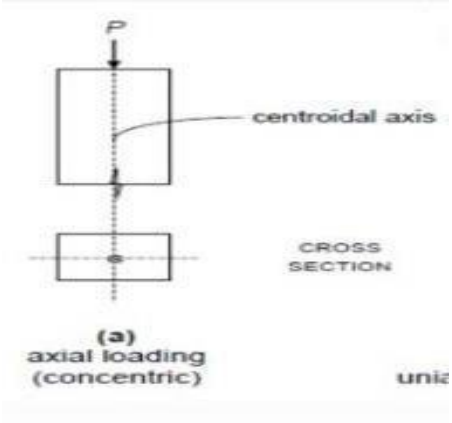


Figure (1 – 9) Axially Load

- **Column with Biaxial Eccentric Loading:** It is a column where the axial load is applied in such a manner that the load produces an eccentric loading in both principal directions concurrently in the plane of the structural member is popularly known as the biaxial loaded column.

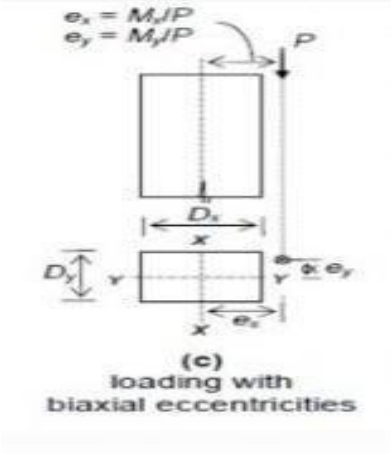


Figure (1 – 10) Biaxial load

b-Uniaxial Load:

- **Column with Uniaxial Eccentric Loading:** A column with Uniaxial Eccentric Loading in a uniaxial eccentric loading column, the vertical loads do not coincide with the center of gravity of column cross-section. The behavior and design of beam-columns are presented within the context of members subjected to uniaxial bending.

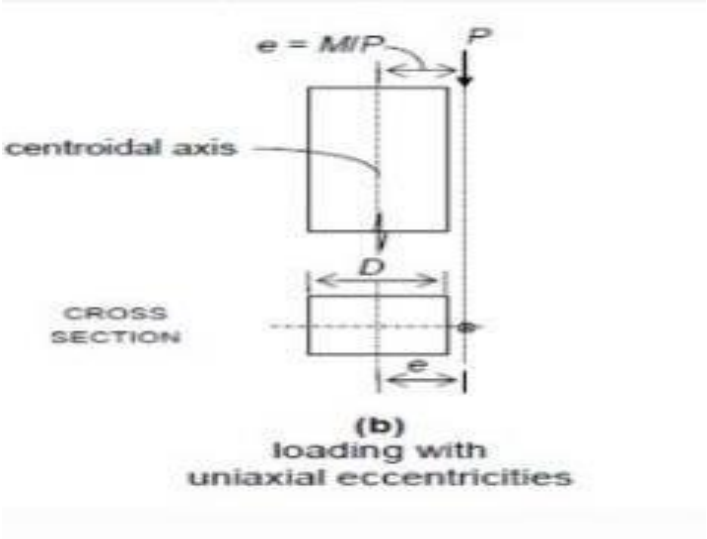


Figure (1 – 11) uniaxial Load

1-3 Failure Column:

- **Pure Compression Failure:** A compression failure occurs when the axial stress exceeds the capacity of a column. Once the axial stress exceeds a certain threshold, that is, producing a strain of concrete that is more than 0.0035, the concrete will instantly collapse, without prior notice.

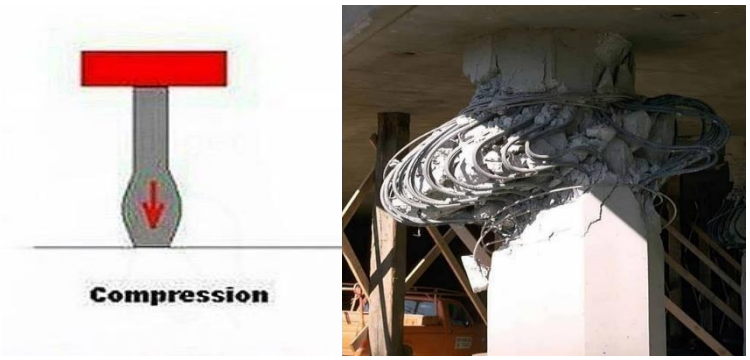


Figure (1 – 12) Compression failure

- **Buckling Failure:** Buckling deflection is a known failure mode, which usually precedes the stresses of axial compression to the point of material deformation by yielding or fracturing the compression member, because instability is what controls the response. Such a failure represents the loss of stability with increasing axial load alone

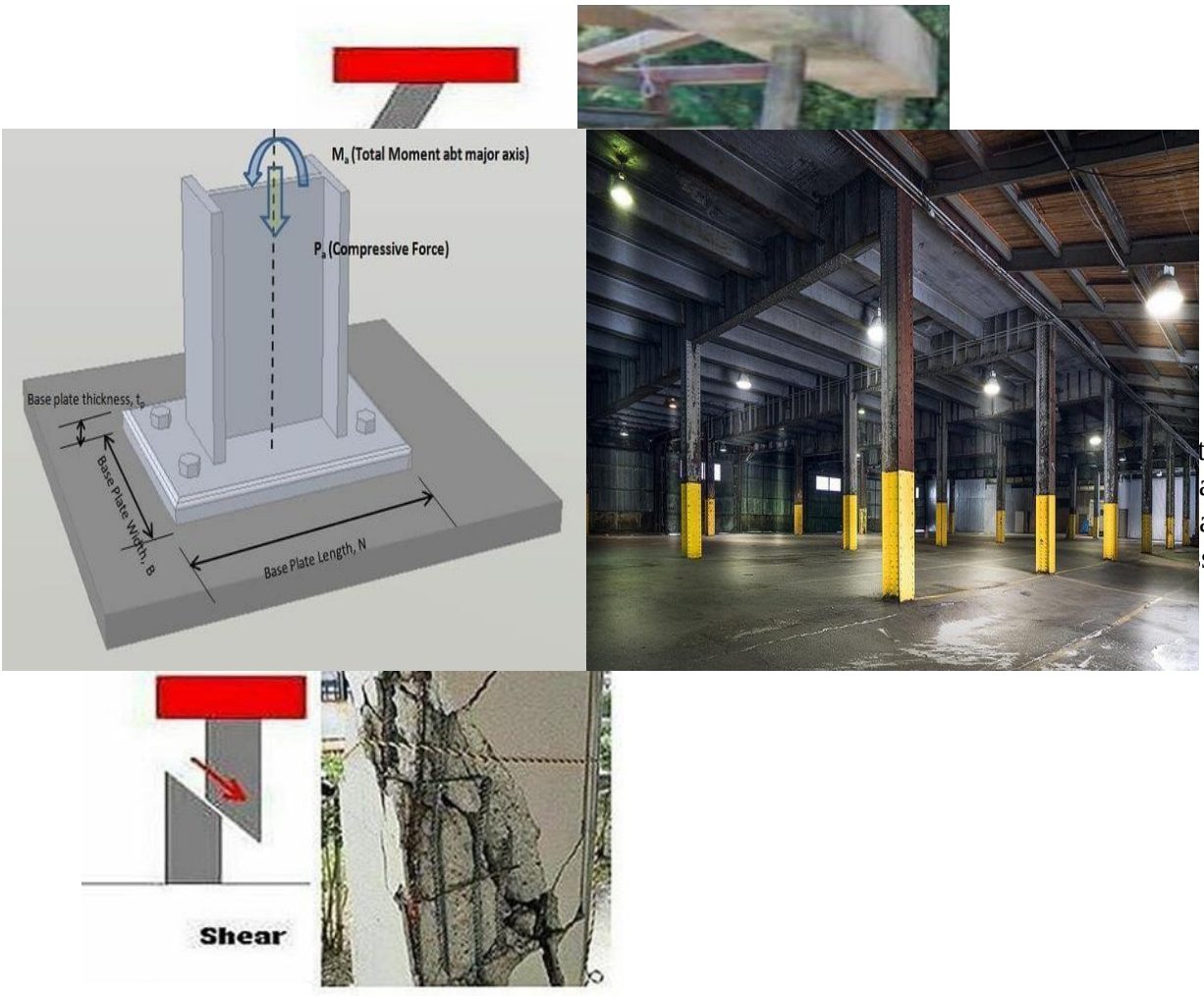


Figure (1 – 14) Shear failure

- **Combine stress failure:** This is any form of stress that cannot be modeled by a single stress component i.e.that is more complex than simple tension, compression or shear and multiple components work in concert

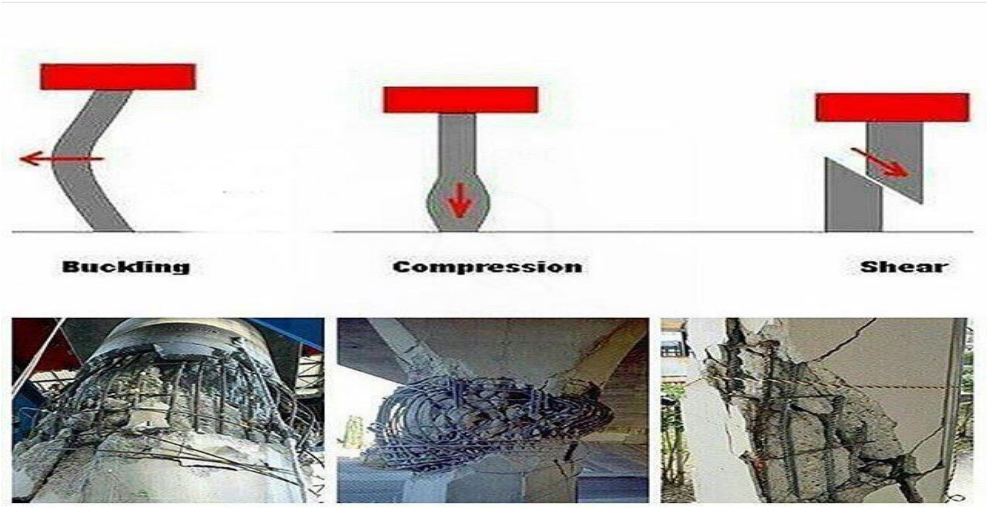


Figure (1 – 15) Stress failure

Torsional: Torsional moments will cause a member to bend around a longitudinal axis through the shear center of the cross-section. When the resultant of acting forces traverses the axis of longitudinal shear center, there will be no twisting, but twisting will always come up. As a rule, torsional moments lead to twisting and warping

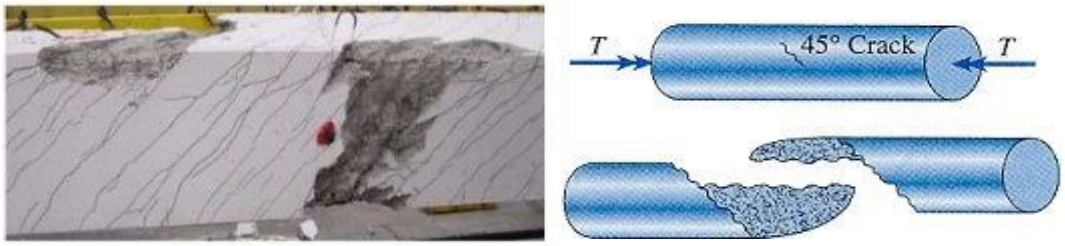


Figure (1-16) Torsion failure

- **Failure by Lack of Confinement Reinforcement:**

This is the possible way of failure of vertical elements which are loaded cyclically. Lack of links in zones of high shear forces is the primary cause of failure. In the structural components, like beams and columns, the increased stress levels occur around the connections. Lack of connections in these locations leads to structural failures during cyclic loads. Equivalent detailing enhances ductility, energy loss and seismic performance. The article Seismic Detailing of Beams and Columns is a good one to follow to understand how the reinforcement should be detailed in order to resist cyclic loading.

Figure (1 – 17) Lack of Confinement

Failures due to errors by designer:

In most cases, the cracking of concrete columns is the result of engineering errors in the design:

1. **Omission of the beam-column relationship:** Beam-column contact is one of the most critical failures of concrete columns that can manifest themselves over time and cause any cracks to be seen. This should be by filling the reinforcing bars and projecting them into the beams along a suitable distance.
2. **Stirrup spacing:** The other thing that contributes to the destruction of concrete columns is that it makes the spacing of the stirrups broader than necessary in columns in general, and in lower stories, especially at the ground floor level.
3. **Lacking precautions:** The other cause of cracking and collapse of the concrete columns is due to the fact that the designer did not take all the possibilities when formulating the engineering design. An example is where several engineers dwell on sound columns, to withstand vertical and live loads, but do not pay much attention to horizontal forces like impact or wind and other forces of nature, making the columns vulnerable to such forces. Moreover, not all of them take precautions related to earthquakes, particularly in areas where

they are not common, which exposes them to the risks of the cracks of columns in case of any kind of shaking.

4. **Construction Causes of Failures:** There are many errors that might happen during the construction, and they might also be classified as the types of column failures. Such column failures will be minimized by using a professional engineer to undertake the project and closely supervising the construction work.

- Weakening the bar with a wrong perception.
- Building a column at the wrong place.
- Alterations in the grade of concrete.
- Lack of strength in the concrete because of failure of the concrete supplier.

2 – 1 Strengthen column:

Strengthen column: Column strengthening is a process used to add or restore ultimate load capacity of reinforced concrete columns.

2-1-1 The reason why strengthening (jacketing) is needed:

The work is very critical as most of the civil structures are no longer judged as safe due to higher load requirements in the building codes, excessive load, poor design of the already built structure or quality control. To ensure efficient serviceability, structures that are old need to be repaired or strengthened to the same requirements that are required by the structures constructed today and in the future. It is also becoming more environmental as well as economically viable to repair or reinforce a structure instead of replacing it wholesomely especially when quick, efficient and easy methods of strengthening are at our disposal.Reinforced concrete columns are to be strengthened when:The load carried by the column is increased due to either increasing the number of floors or due to mistakes in the design.

1. Bearing by the column is enhanced either through addition of floors or design errors.
2. The compressive strength of concrete or the percentage and kind of reinforcement are not met with the requirements of the code.
3. The column inclination is higher than the permissible.

2-1-2 Type Strengthen Column:

1-Concrete Jacketing

2-Steel Jacketing

3- CFRP

2-2 concrete jacketing:

Concrete Jacketing: This is one method of enhancing or reinstating the bearing strength of a reinforced concrete column. The reinforcing bars applied in the stiffening process depend on the structural analysis carried out on the member in terms of the size of the jacket and the number of reinforcing bars and their diameter. Depending on the requirements of the design and purpose of the strengthening, openings can be necessary in slabs and beams to pin the jacket reinforcement in them as specified by the designer.

Figure (2-1) concrete jacket

2-2-1 Purpose of Concrete Jacketing:

Concrete jacketing is needed to provide the bearing capacity after the structural design has been modified, or to reestablish design integrity because of failure in a structural member. This method is applied on walls and columns that are erect, and on mixed sections like beam sides and bottoms.

2-2-2 Concrete Jacketing Process:

1. First, temporary loads on columns should be reduced or eliminated as needed with mechanical jacks and extra supports between floors.
2. When the parts of reinforcement are corroded, excavate the concrete cover and clean the steel bars with a wire brush or sand compressor and apply epoxy substance to stop corrosion.
3. In case load reduction and cleaning are not needed, Jacketing should be started by incorporating steel connectors to the column that is already in place.
4. Install steel connector, drill holes into connector, 3-4 mm bigger than connector size and 10-15 cm deep.
5. Spacing of the new jacket in its vertical and horizontal direction must not be above 80 cm.
6. Use suitable epoxy and place the connectors in the holes.
7. Install vertical steel ties that are used to secure the vertical bars of the jacket as we have done previously in steps 4 and 5.
8. Fit in the new vertical bars and stirrups of the jacket in the designed dimensions and diameters.
9. Apply a suitable epoxy to the column being used to provide a bond between the old and the new concrete.
10. Slop the epoxy then pour the jacket concrete before it cures. To minimize the shrinkage, the concrete must contain low-shrinkage concrete, and the concrete must contain small aggregates, sand, cement, and admixtures

The process of reinforced concrete jacketing follows the steps as shown in the figure below.

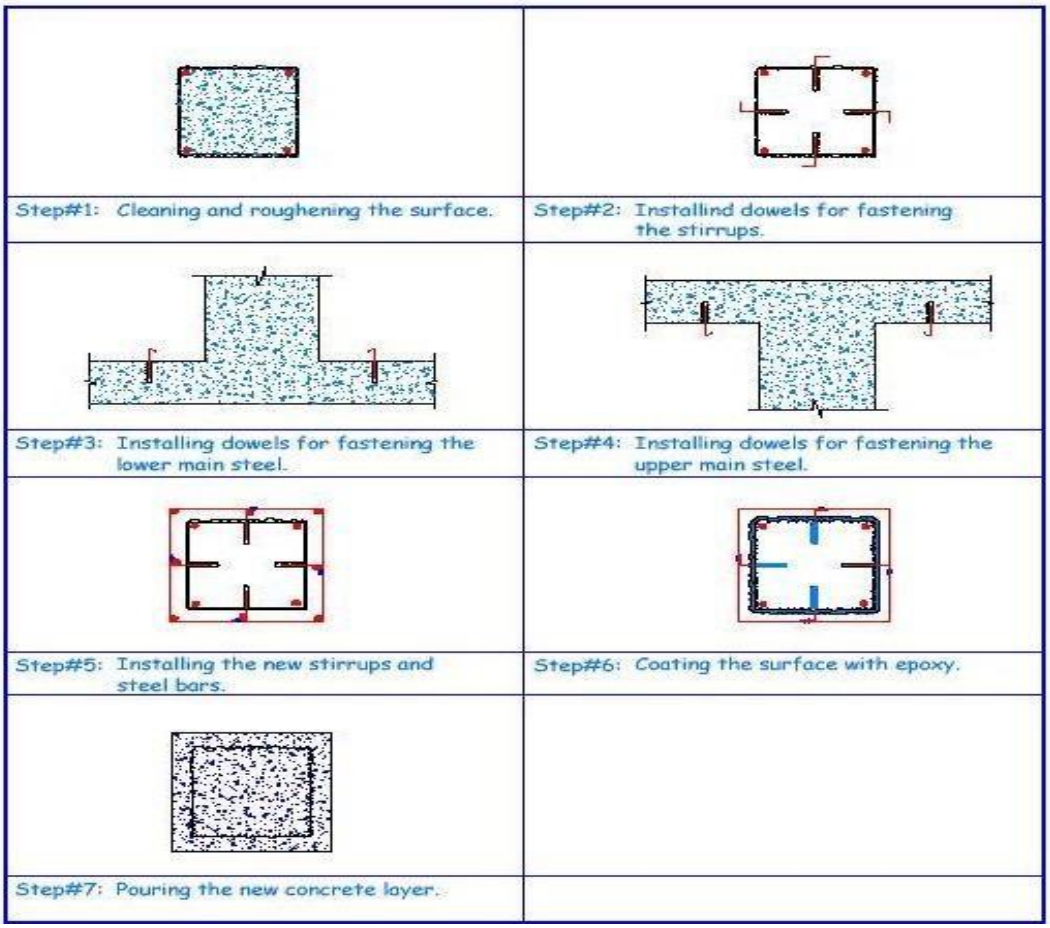


Figure (2-2) Process concrete jacket

2-2-3 The Advantage OF Concrete Jacketing is:

1. Enhances the shear and flexural strength of beams.
2. Enhances compressive property and moment carrying capacity of columns.
3. Ease of construction.
4. Noble materials can be easily sourced.

2-2-4 Disadvantage of Jacketing:

1. Section sizes are expanded leaving us with less available free space.
2. A large dead mass is added.
3. Has to have sufficient dowelling to the column in place.
4. The longitudinal bars have to be fixed on the foundation and they have to extend in the slab.
5. Involves the holes to be drilled in the pre-existing columns, slabs, beams, and footings.
6. Fixing of ties at beam-column joints is impractical.
7. It is low in terms of the speed of implementation.

2-3 Steel Jacketing:

Steel Jacketing: This technology is chosen when the loads applied to the shaft are increased, and at the same time, it is not allowed to increase the crosssectional area of the column. It has many different applications such as separate annular reinforcement over the entire height of the column and the use of steel corners in the corners and other applications specified by the designer where the most important goal is to obtain a strong bond with the old shaft under the influence of all the conditions of its loading and the direction of forces and its transmission. The roof, beams or not depends on the purpose of the reinforcement.

Figure (2-4) Steel Jacketing

1. Purpose of steel jacketing:

The process of enclosing reinforced concrete (RC) columns with steel jackets is also a good method of enhancing fundamental strength capacity.

2. Steel Jacketing Process:

1. A layer of an epoxy material should be applied on strengthening bars to ensure they do not corrode.
2. Attach the steel jacket to the right size and thickness as per the design and provide vent holes through which to inject epoxy to provide the necessary bond between the concrete and the steel jacket.
3. Stuff the annular space between the concrete column and the steel jacket with an appropriate epoxy material. All these will offer confinement, improve load transfer among materials, and

aid in restoring or enhancing the action of the strengthened member under service and ultimate conditions, which would be compositive.

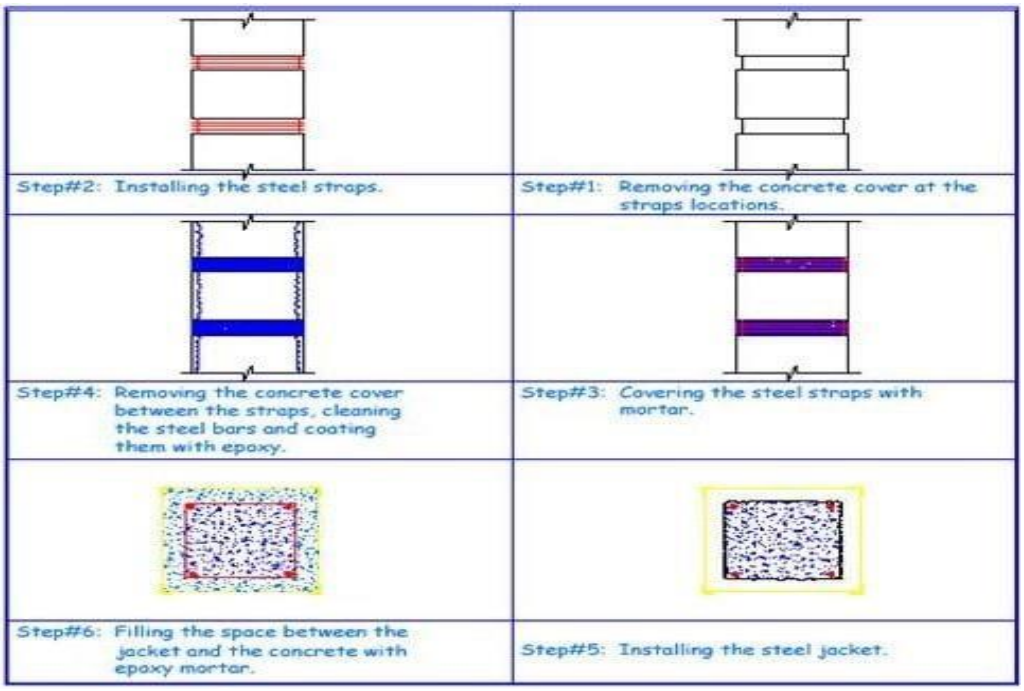


Figure (2-4) Steel Jacketing Process

3. Advantage of Steel Jacketing:

1. Easily supplies high volume of transverse steel hence in the process provides good confinement to compressed concrete.
2. Stops the spalling of the outer shell concrete.
3. This system does not increase the size of the RC column footprint and it provides sufficient durability along with the simplicity in use.

2-3-4 Disadvantages OF steel Jacketing:

steel work might be labor consuming, it might need heavy machinery to work with large tonnages and it might need more complicated services. The limitations of the site, restrictions in access, and demands of accurate tolerances in the fabrications contribute to the difficulty of execution, and may lengthen schedules and increase the cost of the entire project compared to easier repair alternatives. Continuous checking and protective finishes are usually necessitated in order to achieve durability in the long term.

4. Carbon Fiber Reinforced Polymer (CFRP):

Carbon Fiber Reinforced Polymer (CFRP): Carbon fiber reinforced polymer (CFRP) is a composite material which is composed of carbon fibers incorporated into a polymer matrix. Embedded CFRP reinforcement bars on new cement can remove the possible corrosion issues and significantly enhance the structural strength of a member.

Figure (2-5) CFRP

2-4-1 How is CFRP produced?

CRFP can be produced using multiple production routes with each having its own benefits in terms of cost of production and/or property spectrum with respect to the intended usage. The carbon fiber forms the beginning of any process of manufacturing CFRP. The fibers are woven or laid into a fabric, or even wound or plied by a technique referred to as the textile industry. The production of CFRP components can be provided by series production and prototype. The production technologies involved are the following:

prepare compression molding

- Autoclave technology
- Winding methods
- Blowing methods
- Resin transfer Molding (RTM process).
- Wet pressing
- Braiding
- Tape laying Figure (3-6) components CFRP
- Fiber placement

The right diagram shows various processes of producing a CFRP piece.

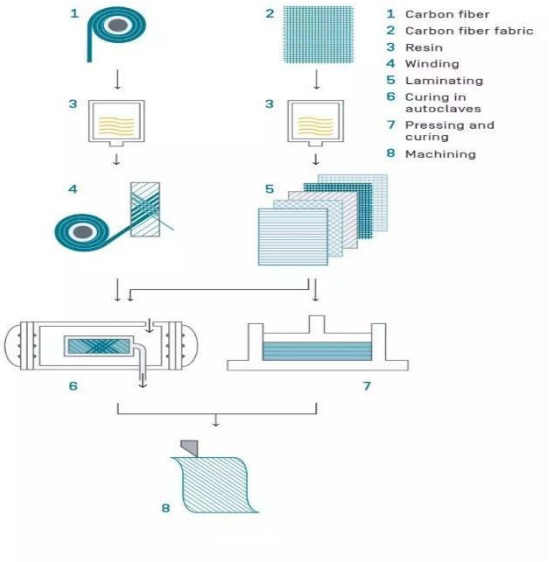


Figure (3-6) components CFRP

2 Properties CFRP:

These high-tech composites are characterized by high load bearing capacity, low density, high toughness, low damage tolerance, high strength, high hardness, lightness, low friction coefficient, good wear resistance, chemical and dimensional stability and resistance to corrosion.

2-4-3 Purpose of CFRP:

CFRP finds extensive application during strengthening and repair of reinforced concrete structures.

2-4-4 CFRP Process:

Surface treatment

- Apply HM-180 primer
- May have to repair and even with HM-180CE leveling adhesive.
- Using HM-180C3P carbon-fiber adhesive.
- Externally bond unidirectional carbon fiber wrap (Horse).
- Use HM-180C3P -3P carbon-fiber adhesive again.
- Offer Curing and protection

5 Advantages of CFRP:

1. Enhances the final load and carrying capacity of a reinforced concrete member.
2. Enhances the shear strength of the reinforced concrete element.
3. Increases the reinforced bar lap-splice strength because of the FRP axial strengthening system.
4. Enhances the strength of the reinforced concrete column greatly in terms of ductility.

2-4-6 Disadvantage of CFRP:

1. There is the possibility of low, immeasurable quality of the products, especially the smaller products, where it is extremely difficult, to the point of being virtually impossible to know, based on the outward appearance alone.
2. High cost. Carbon fibers are not common in mass production in spite of their fine performance.The production cost of CFRP composite is currently high. Depending on the supply and demand, the type of carbon-fiber (aerospace or commercial grade), and the size of the fiber-bundles, the price will be different.

7 Define FRP

Fiber-reinforced plastic (FRP): FRP is a composite that consists of a polymer structure that has fibers attached to give it strength. It is popular in the aerospace, construction, and marine industry to construct structures that need to be reinforced against forces to avoid deformation. Corrosion protection FRP is also useful in corrosion protection due to the prevention of corrosion under the application of force and deformation like stress-corrosion cracking

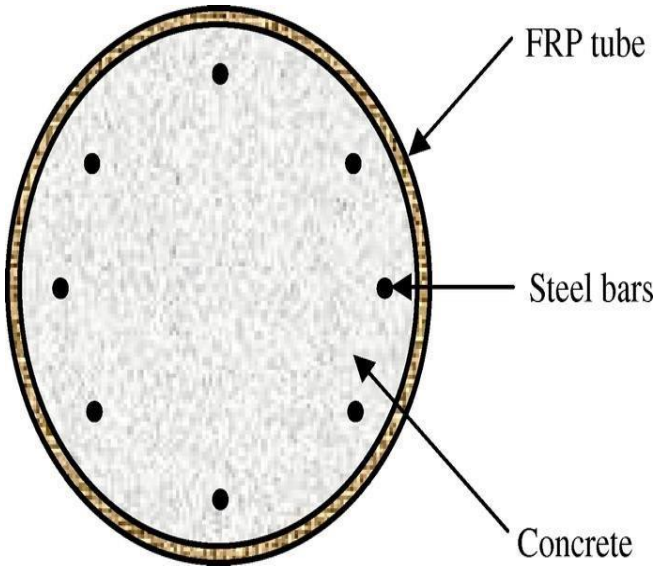


Figure (2-7) FRP

2-4-8 Compare between CFRP & FRP?

Composite materials, reinforced with carbon fiber, are different than other FRP composites using traditional materials such as fiberglass or aramid fiber. ... Increased Strength: Not only are carbon fiber composites lighter weight, but CFRP composites are much stronger and stiffer per unit of weight.

3-1 Procure calculation:

3-1-1 How do you know strengthen is necessary?

1. First select column
2. Find the largest applied load to column

3. calculate the column bearing strength according to equation Pu=0.8Ø[0.85*fc(Ag-As) +As*fy]
4. Calculate load according to equation [Load=1.2 *D.L+1.6*L.L] 5-Then we compare the load with bearing strengthen of column if applied load < column bearing strength __ ok if applied Load > column bearing strength __ Not ok (need Strengthening)

3-1-2 strengthen by concrete jacketing:

1. Calculate load (live load & dead load)

2-Cutting the concrete cover & calculate b` & t`

3-We calculate Area core

4- Calculate column core bearing strength according to equation

Pu(core)=0.8Ø[0.85*fc(Ag-As) + As*fy]

5.That must be bearing strength increased

(Pu) jacketing= load applied to columns – (Pu) core

6- Assume (A steel) jacketing=0.01Ajacketing, calculate A jacketing according to equation {Pu(core)=0.8Ø[0.85*fc(Aj-Astj)+Astj*fy]}

7-We calculate (tj) equation Aj=[(b`+2tj)+( t`+2tj)]-(t` *b`) ,but according to

ASTM standard {tj>= 80 mm}

8-if tj was larger 80 mm Aj don't need to change, but lower 80 mm,we calculate

Aj again &we calculate Astj according equation {Astj=0.01 Aj}

9-shear connector:

Puj=pu friction +pu connector

Assuming pu friction =0

10-we calculate the number connector according equation

Number of connectors=

10.RFT details:

150mm =<p >=300mm

P=distance between shear key

11-We put 1 steel bar in each strip corner & each shear key corner, then we put a steel bar between each 2 steel bar, after that we calculate spacing between steel bar.

12-applied load (of one bar) = $\frac{\text{pu jacketing}}{\text{number of reinforcement}}$

3-1-3 strengthen by steel jacketing:

1-Applied load columns–column bearing strength= That must be bearing strength increased

2-We select angle section that available hardware store

3.We Calculate the area section angle

4.Because of the knowledge of the area, we can find r according to equation

$r=\sqrt{\frac{I}{A}}$

5-We calculate L= $\frac{height\ column}{the\ number\ of\ spaces\ between\ steel\ belt}$

6-We calculate function ($\frac{K*L}{r}$) find Ø*fcr (stress) in manual steel

7-P=stress*Area section angle

8-If P*number of angle section< That bearing strength must be increased

9-(Not ok) try another angle section

10-If P*number of angle section> That bearing strength must be increased (ok)

11-check section according equation

Pu=0.8Ø[0.85* fć(Ag-Ast)+Ast*fy]+4(AS*fy)(steel)> applied load columns

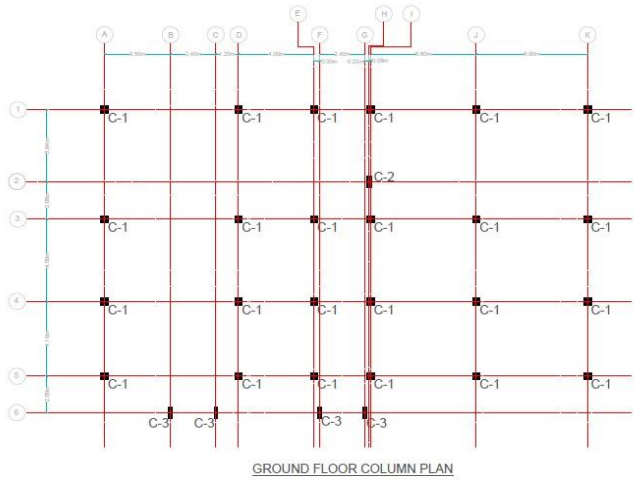
Table 4-22
Available Critical Stress for Compression Members

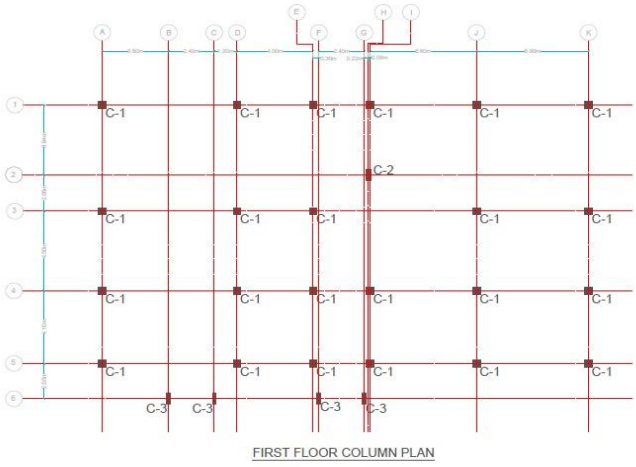
F_y = 35 ksi			F_y = 36 ksi			F_y = 42 ksi			F_y = 46 ksi			F_y = 50 ksi		
$\frac{KL}{r}$	F_{cr}/Ω_c ksi	$\phi_c F_{cr}$ ksi	$\frac{KL}{r}$	F_{cr}/Ω_c ksi	$\phi_c F_{cr}$ ksi	$\frac{KL}{r}$	F_{cr}/Ω_c ksi	$\phi_c F_{cr}$ ksi	$\frac{KL}{r}$	F_{cr}/Ω_c ksi	$\phi_c F_{cr}$ ksi	$\frac{KL}{r}$	F_{cr}/Ω_c ksi	$\phi_c F_{cr}$ ksi
	ASD	LRFD		ASD	LRFD		ASD	LRFD		ASD	LRFD		ASD	LRFD
1	21.0	31.5	1	21.6	32.4	1	25.1	37.8	1	27.5	41.4	1	29.9	45.0
2	21.0	31.5	2	21.6	32.4	2	25.1	37.8	2	27.5	41.4	2	29.9	45.0
3	20.9	31.5	3	21.5	32.4	3	25.1	37.8	3	27.5	41.4	3	29.9	45.0
4	20.9	31.5	4	21.5	32.4	4	25.1	37.8	4	27.5	41.4	4	29.9	44.9
5	20.9	31.5	5	21.5	32.4	5	25.1	37.7	5	27.5	41.3	5	29.9	44.9
6	20.9	31.4	6	21.5	32.3	6	25.1	37.7	6	27.5	41.3	6	29.9	44.9
7	20.9	31.4	7	21.5	32.3	7	25.1	37.7	7	27.5	41.3	7	29.8	44.8
8	20.9	31.4	8	21.5	32.3	8	25.1	37.7	8	27.4	41.2	8	29.8	44.8
9	20.9	31.4	9	21.5	32.3	9	25.0	37.6	9	27.4	41.2	9	29.8	44.7
10	20.9	31.3	10	21.4	32.2	10	25.0	37.6	10	27.4	41.1	10	29.7	44.7
11	20.8	31.3	11	21.4	32.2	11	25.0	37.5	11	27.3	41.1	11	29.7	44.6
12	20.8	31.3	12	21.4	32.2	12	24.9	37.5	12	27.3	41.0	12	29.6	44.5
13	20.8	31.2	13	21.4	32.1	13	24.9	37.4	13	27.2	40.9	13	29.6	44.4
14	20.7	31.2	14	21.3	32.1	14	24.8	37.3	14	27.2	40.9	14	29.5	44.4
15	20.7	31.1	15	21.3	32.0	15	24.8	37.3	15	27.1	40.8	15	29.5	44.3
16	20.7	31.1	16	21.3	32.0	16	24.8	37.2	16	27.1	40.7	16	29.4	44.2
17	20.7	31.0	17	21.2	31.9	17	24.7	37.1	17	27.0	40.6	17	29.3	44.1
18	20.6	31.0	18	21.2	31.9	18	24.7	37.1	18	27.0	40.5	18	29.2	43.9
19	20.6	30.9	19	21.2	31.8	19	24.6	37.0	19	26.9	40.4	19	29.2	43.8
20	20.5	30.9	20	21.1	31.7	20	24.5	36.9	20	26.8	40.3	20	29.1	43.7
21	20.5	30.8	21	21.1	31.7	21	24.5	36.8	21	26.7	40.2	21	29.0	43.6
22	20.4	30.7	22	21.0	31.6	22	24.4	36.7	22	26.7	40.1	22	28.9	43.4
23	20.4	30.7	23	21.0	31.5	23	24.3	36.6	23	26.6	40.0	23	28.8	43.3
24	20.3	30.6	24	20.9	31.4	24	24.3	36.5	24	26.5	39.8	24	28.7	43.1
25	20.3	30.5	25	20.9	31.4	25	24.2	36.4	25	26.4	39.7	25	28.6	43.0
26	20.2	30.4	26	20.8	31.3	26	24.1	36.3	26	26.3	39.6	26	28.5	42.8
27	20.2	30.3	27	20.7	31.2	27	24.0	36.1	27	26.2	39.4	27	28.4	42.7
28	20.1	30.3	28	20.7	31.1	28	24.0	36.0	28	26.1	39.3	28	28.3	42.5
29	20.1	30.2	29	20.6	31.0	29	23.9	35.9	29	26.0	39.1	29	28.2	42.3
30	20.0	30.1	30	20.6	30.9	30	23.8	35.8	30	25.9	39.0	30	28.0	42.1
31	20.0	30.0	31	20.5	30.8	31	23.7	35.6	31	25.8	38.8	31	27.9	41.9
32	19.9	29.9	32	20.4	30.7	32	23.6	35.5	32	25.7	38.6	32	27.8	41.8
33	19.8	29.8	33	20.4	30.6	33	23.5	35.4	33	25.6	38.5	33	27.7	41.6
34	19.8	29.7	34	20.3	30.5	34	23.4	35.2	34	25.5	38.3	34	27.5	41.4
35	19.7	29.6	35	20.2	30.4	35	23.3	35.1	35	25.4	38.1	35	27.4	41.2
36	19.6	29.5	36	20.1	30.3	36	23.2	34.9	36	25.2	37.9	36	27.2	40.9
37	19.5	29.4	37	20.1	30.1	37	23.1	34.8	37	25.1	37.8	37	27.1	40.7
38	19.5	29.3	38	20.0	30.0	38	23.0	34.6	38	25.0	37.6	38	26.9	40.5
39	19.4	29.1	39	19.9	29.9	39	22.9	34.4	39	24.9	37.4	39	26.8	40.3
40	19.3	29.0	40	19.8	29.8	40	22.8	34.3	40	24.7	37.2	40	26.6	40.0

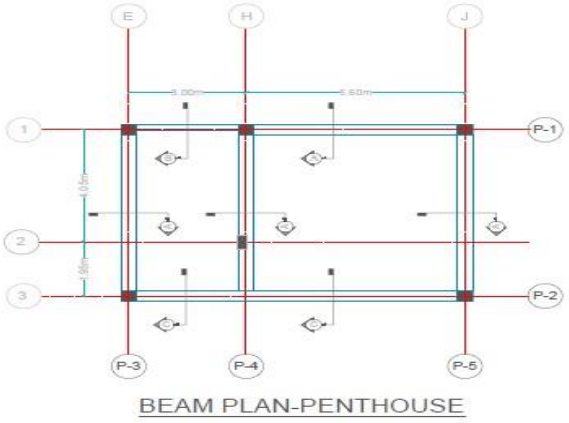
ASD	LRFD
Ω_c = 1.67	ϕ_c = 0.90

Table (3-1) Manual steel

3-2-1 Building Design:







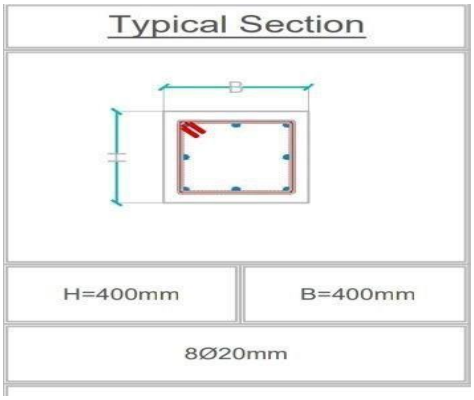


Figure (3-1) Building design

Material	ɣ	t(cm)
Brick	20	40
Water proof	15	2
Soil under tiles mortar	17	10
Tiles mortar	23	5
Slab	24	20

Table (3-2) Unit weight 3-2-2: calculation:

31- Then we compare the applied load with bearing strengthen of column Select column (c1) largest Area=5.75*5.25

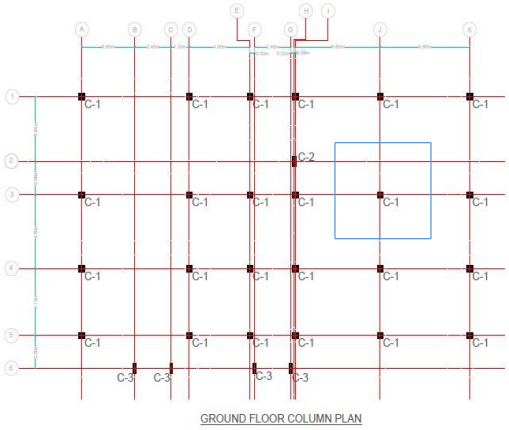
Area pen house=3*2.8 (1kg= 0.00980665 kn) fć=25 Mpa , fy=400Mpa, h=3.2m , nf=2

L.L(ground)=300kg/m² , L.L(1st,penhouse)= 200 kg/m²

L.L (total)=500*5.25*5.75+3*2.8*200=16773.75 kg=164.38 kn

Ag=400²=16*10⁴ mm²

Ast=



Pu=0.8Ø[0.85* fć(Ag-Ast)+Ast*fy]

Pu=0.8*0.65[0.85*25*(16*10^4-2513.2)+ 2513.2*400]=2262.97 kn Thickness slab=20cm

D.L (slab)=24*5.75*5.25*0.2+3*2.8*24*0.2=330.12 kn thickness brick=40 cm

D.L(brick)=0.4*20*3.2[(5.75+5.25)+(3+2.8)]=430.08 kn beam=0.4*0.5=0.2m²

D.L(beam)=2(0.2*24*(5.75+5.25))+((2.8+3)*0.2)=133.44 kn column=0.4²=0.16

D.L(column)=3.2*0.16*2*24=24.576 kn tiles mortar=5cm

D.L(tiles mortar) =0.05*23[(5.25*5.75)+(2.8+3)]=44.37 kn water proof=2cm, soil under mortar tiles=10 cm

D.L=5.25*5.75*0.02*15+5.25*5.75*23*0.05+5.25*5.75*0.1*17=95.07 kn summation dead load

D.L(total)=95.07+44.37+24.576+133.44+430.08+330.12=1057.656 kn wu=1.2*d.L+1.6*L.L wu=1.2*1057.656+1.6*164.38=1532.195 < 2262.97 kn safe sade (do not need strengthen)

2-We need change building in to 4 floors, then we compare the load with bearing strengthen of column:

largest Area=5.75*5.25 Area pen house=3*2.8 fć=25 Mpa , fy=400Mpa, h=3.2m , nf=2

L.L(ground,1^{st},2^{nd})=300kg/m² , L.L(3^{rd},penhouse)=200 kg/m²

Ag=400²=16*10^4 mm²

Ast=

Pu=0.8Ø[0.85* fć(Ag-Ast)+Ast*fy]

Pu=0.8*0.65[0.85*25*(16*10^4-2513.2)+ 2513.2*400]=2262.97 kn

L.L(ground,1^{st},2^{nd},3^{rd})=1100kg/m²=10.78 kn/m²*5.75*5.25=325.4 kn

Thickness slab=20cm

D.L (slab)=24*5.75*5.25*0.2*4=579.6 kn thickness brick=40 cm

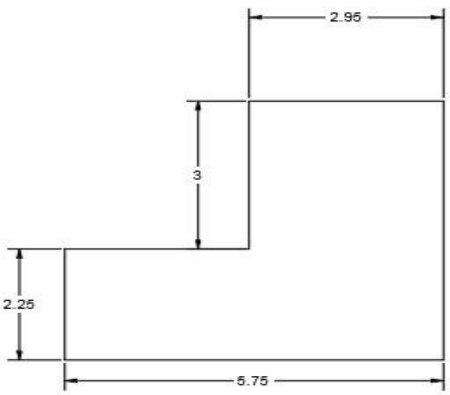
D.L(brick)=0.4*20*3.2*3(5.75+5.25)=844.8 kn beam=0.4*0.5=0.2m²

D.L(beam)=4*0.2*24*(5.75+5.25)=211.2 kn column=0.4²=0.16

D.L(column)=3.2*0.16*4*24=36.86 kn

D.L(tiles mortar) =0.05*23[(5.25*5.75)*3+(2.8+3)]=113.8 kn

water proof=2cm, soil under mortar tiles=10 cm



Area=2.95*3+2.25*5.75=21.78 m²

d.L=21.78*0.02*15+21.78*23*0.05+21.78*0.1*17=68.6 kn

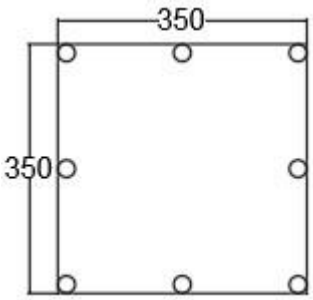
L.L=1.96*3*2.8=16.46

d.L=24*3*2.8*0.2+0.4*20*3.2*5.8+0.2*24*5.8+3.2*0.16*24+ 2.8*3*23*0.05+15*0.02*3*2.8+0.1*17*3*2.8 = 255.38 kn wu=1.2*d.L+1.6*L.L wu(pen house)=1.2*255.38+1.6*16.46=332.79 kn summation dead load

d.L(total)=68.6+113.8+211.2+36.86+844.8+579.6=1854.86 kn wu1=1.2*d.L+1.6*L.L wu1=1.2*1845.86+1.6*325.4=2746.5 wu1+wu (pen house)

2746.5+332.79=3079.3 kn < 2262.97 kn not safe side (need strengthen)

2. **strengthen by concrete jacketing:**



t`=400-50=350 b`=b-50=350

Ag core =350²=122500 mm²

Pu=0.8Ø[0.85* fć(Ag-Ast)+Ast*fy]

Pu core=0.8*0.65[0.85*25*(122500-2513.2)+

2513.2*400]=1848.6 kn

Pu jacket = pu act- pu core

Pu jacket=3079.3-1848.6=1230.7 kn

Asj=0.01*Aj

Pu =0.8Ø[0.85* fć(Ag-Ast)+Ast*fy]

Pu jacket(1230.7)=0.8*0.65[0.85*25*(Aj-0.01Aj)+ Aj*0.01*400]

Aj=94596 mm²

Aj=[(b`+2tj)+( t`+2tj)]-(t` *b`)

Aj(94596)=[(350+2tj)+(350`+2tj)]-(350²)

By try error: tj=58

94596=<94656 tj= 58 <80 not ok tj=80 mm minimum tj

Aj=[(b`+2tj)+( t`+2tj)]-(t` *b`)

Aj=[(350+2*80)+(350`+2*80)]-(350²)=137600 mm² Asj=0.01*137600=1376 mm² Shear connector:

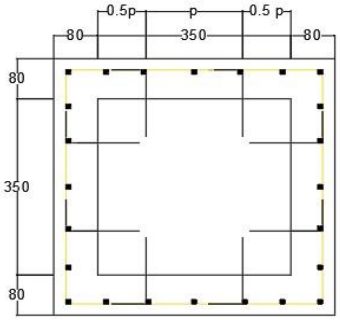
Puj=pu friction +pu connector

Pu friction= zero

Puj =pu connector=

12Ø

AØ= $\frac{12^2*\pi}{4}$=113



Number of connectors= $\frac{pu\ conector*\gamma s}{0.8*fy*A\emptyset}$

Number of connectors= $\frac{1230.7*1.15}{0.8*400*113}$= 39.15=40

RFT details:

150mm =< p >= 300 mm

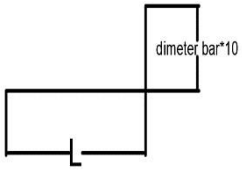
2p=350mm

P=175 mm

L=10Ø(tj-cover concrete)

L=120(80-25)=175mm

Spacing = $\frac{510-50*2-7*12}{6}$ =54.3 mm > 25 mm



As one bar = $\frac{1230.7}{24}$ =57.3 kn

24 Ø10

4-strenthen by steel jacketing:

H=3.2m

L=70mm,h=70mm,t=6mm

Pu act=3079.3 kn

Pu columns= 2262.97 kn

Pu jacketing=3079.3-2262.97=816.33 kn

Load by one section angle= $\frac{816.33}{4}$ =204.1 kn

L= $\frac{3.2}{4}$ =0.8m=31.4961 in (1m=39.37in) Figure (3-2) Angle section **Figure (3-2) Angle section**

K=1

A=70*6+70*6-6²=804 mm²=1.2462in²(1 mm²= 0.00155 in²)

r= $\sqrt{\frac{I}{A}}$

y= $\frac{\sum A*dy}{\sum A}$

assume (n.x) in bottom:

$y=\frac{3*70*6+65*6*35}{804}$ =18.54 mm

$I=\frac{b*h^3}{12}$ +A*(dy)²

$I=\frac{70*6^3}{12}+6*70*15.54^2+\frac{65^3*6}{12}+65*6*16.46^2=345661.198\ mm^4$

$r=\sqrt{\frac{345661.198}{804}}$ =20.73 mm=0.816 in

$\frac{k*L}{r}$ =38 Stress(LRFD)=40.5 ksi (table below)

$\frac{k*L}{r}$ =39 Stress(LRFD)=40.3 ksi (table below)

$$\frac{0.2}{1}=\frac{x}{0.4}$$

X=0.08

$\frac{k*L}{r}$ =38.6 Stress(LRFD)=40.3+0.08=40.38 ksi

P=stress*Area

P=40.38*1.2462=50.32 kips =223.83 kn >204.1 ok (1kips= 4.4482 kn)

Checking:

Pu=0.8Ø[0.85* fć(Ag-Ast)+Ast*fy]+(AS*fy)(steel)

Pu=0.8*0.65[0.85*25 ($16*10^4$-2513.2)+ 2513.2*400]+

344.738*4*804=3372.5kn

Compare with load:

3372.5 kn > 3079.3 kn (ok safe side)

$F_y = 35$ ksi			$F_y = 36$ ksi			$F_y = 42$ ksi			$F_y = 46$ ksi			$F_y = 50$ ksi		
$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD	$\frac{KL}{r}$	F_{cr}/Ω_c ksi ASD	$\phi_c F_{cr}$ ksi LRFD
1	21.0	31.5	1	21.6	32.4	1	25.1	37.8	1	27.5	41.4	1	29.9	45.0
2	21.0	31.5	2	21.6	32.4	2	25.1	37.8	2	27.5	41.4	2	29.9	45.0
3	20.9	31.5	3	21.5	32.4	3	25.1	37.8	3	27.5	41.4	3	29.9	45.0
4	20.9	31.5	4	21.5	32.4	4	25.1	37.8	4	27.5	41.4	4	29.9	44.9
5	20.9	31.5	5	21.5	32.4	5	25.1	37.7	5	27.5	41.3	5	29.9	44.9
6	20.9	31.4	6	21.5	32.3	6	25.1	37.7	6	27.5	41.3	6	29.9	44.9
7	20.9	31.4	7	21.5	32.3	7	25.1	37.7	7	27.5	41.3	7	29.8	44.8
8	20.9	31.4	8	21.5	32.3	8	25.1	37.7	8	27.4	41.2	8	29.8	44.8
9	20.9	31.4	9	21.5	32.3	9	25.0	37.6	9	27.4	41.2	9	29.8	44.7
10	20.9	31.3	10	21.4	32.2	10	25.0	37.6	10	27.4	41.1	10	29.7	44.7
11	20.8	31.3	11	21.4	32.2	11	25.0	37.5	11	27.3	41.1	11	29.7	44.6
12	20.8	31.3	12	21.4	32.2	12	24.9	37.5	12	27.3	41.0	12	29.6	44.5
13	20.8	31.2	13	21.4	32.1	13	24.9	37.4	13	27.2	40.9	13	29.6	44.4
14	20.7	31.2	14	21.3	32.1	14	24.8	37.3	14	27.2	40.9	14	29.5	44.4
15	20.7	31.1	15	21.3	32.0	15	24.8	37.3	15	27.1	40.8	15	29.5	44.3
16	20.7	31.1	16	21.3	32.0	16	24.8	37.2	16	27.1	40.7	16	29.4	44.2
17	20.7	31.0	17	21.2	31.9	17	24.7	37.1	17	27.0	40.6	17	29.3	44.1
18	20.6	31.0	18	21.2	31.9	18	24.7	37.1	18	27.0	40.5	18	29.2	43.9
19	20.6	30.9	19	21.2	31.8	19	24.6	37.0	19	26.9	40.4	19	29.2	43.8
20	20.5	30.9	20	21.1	31.7	20	24.5	36.9	20	26.8	40.3	20	29.1	43.7
21	20.5	30.8	21	21.1	31.7	21	24.5	36.8	21	26.7	40.2	21	29.0	43.6
22	20.4	30.7	22	21.0	31.6	22	24.4	36.7	22	26.7	40.1	22	28.9	43.4
23	20.4	30.7	23	21.0	31.5	23	24.3	36.6	23	26.6	40.0	23	28.8	43.3
24	20.3	30.6	24	20.9	31.4	24	24.3	36.5	24	26.5	39.8	24	28.7	43.1
25	20.3	30.5	25	20.9	31.4	25	24.2	36.4	25	26.4	39.7	25	28.6	43.0
26	20.2	30.4	26	20.8	31.3	26	24.1	36.3	26	26.3	39.6	26	28.5	42.8
27	20.2	30.3	27	20.7	31.2	27	24.0	36.1	27	26.2	39.4	27	28.4	42.7
28	20.1	30.3	28	20.7	31.1	28	24.0	36.0	28	26.1	39.3	28	28.3	42.5
29	20.1	30.2	29	20.6	31.0	29	23.9	35.9	29	26.0	39.1	29	28.2	42.3
30	20.0	30.1	30	20.6	30.9	30	23.8	35.8	30	25.9	39.0	30	28.0	42.1
31	20.0	30.0	31	20.5	30.8	31	23.7	35.6	31	25.8	38.8	31	27.9	41.9
32	19.9	29.9	32	20.4	30.7	32	23.6	35.5	32	25.7	38.6	32	27.8	41.8
33	19.8	29.8	33	20.4	30.6	33	23.5	35.4	33	25.6	38.5	33	27.7	41.6
34	19.8	29.7	34	20.3	30.5	34	23.4	35.2	34	25.5	38.3	34	27.5	41.4
35	19.7	29.6	35	20.2	30.4	35	23.3	35.1	35	25.4	38.1	35	27.4	41.2
36	19.6	29.5	36	20.1	30.3	36	23.2	34.9	36	25.2	37.9	36	27.2	40.9
37	19.5	29.4	37	20.1	30.1	37	23.1	34.8	37	25.1	37.8	37	27.1	40.7
38	19.5	29.3	38	20.0	30.0	38	23.0	34.6	38	25.0	37.6	38	26.9	40.5
39	19.4	29.1	39	19.9	29.9	39	22.9	34.4	39	24.9	37.4	39	26.8	40.3
40	19.3	29.0	40	19.8	29.8	40	22.8	34.3	40	24.7	37.2	40	26.6	40.0

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2 – 1 Jacketing:

3.1.7 Shear key:

- Drill holes of specified diameter and depth to receive shear key.
- Clean the drilled holes by blowing air.
- Inject epoxy bonding paste in drilled holes to fill t from ends to half of the Holes.
- Insert "L" shaped shear Key and allow epoxy to cure.