

AL FARSHAH PHCC EXTENSION YEMEN

Engineering
Services Unit

2026

March 2026

YEMEN FLECS Engineering
Consulting

Email - yahyaalgysi@gmail.com

Mobile _ 00967-- 777800603



AL FARSHAH PHCC EXTENSION -- Tur Albahah - Lahij Governorate

This report was
prepared for



About

This technical report is presented to establish the structural engineering framework for the expansion project of **Al Farshah Health Center**, funded by Doctors Without Borders / Médecins Sans Frontières (MSF) and located in Al Farshah area. The project aims to increase the operational capacity of the existing medical facility and enhance the Primary Health Care Center and Basic Emergency Obstetric and services provided to the local community. The report examines the proposed master layout along with the physical and structural connection between the new extension and the existing facility, ensuring safety and structural stability for both structures. It also reviews the analysis of expected loads, the selection of the approved structural system for the concrete frame, and the appropriate foundation system for the new architectural mass. Furthermore, the report outlines the engineering solutions adopted to handle the structural interface and connection points between the two buildings to ensure sound structural integration. Finally, it specifies the applicable structural codes, technical specifications, and standards required to ensure high-quality execution and construction accuracy.."

PHOTO ON COVER

© YEMEN FLECS – Eng . Fayza Al-Haj 2018-

Reports Team



YEMEN FLECS Engineering Consulting

Republic of Yemen

Lahj Office - Green City - Tel: 777800603

Sana'a Office - West 60th Street - Tel: 777800603

Email – yahyaalgysi@gmail.com

Mobile _ 00967– 777800603

Engineering Services Unit

2026



2026

Engineering Services Unit

Eng- Yahya Ahmed AL-Qaisi

Eng- Omar Ahmed Hussien

Eng- Basam Abdilkareem Haydar

Eng- Fayza Mohammed Ali



Field Visit Team

Eng- Fares Badeh Obad



LOCATION: Tur Albahah - ALFARSHAH

GPS coordinates : 13.132174191808623, 44.41869049947498



Structural Design Technical Report Summary

Expansion Project for Al Farshah Health Center (Funded by Médecins Sans Frontières / MSF)

1. Scope & Purpose

This technical report establishes the structural engineering framework and standards adopted for the expansion project of Al Farshah Health Center. The purpose of this report is to document the applied codes and technical specifications, define the properties of structural materials, and ensure the safety, stability, and proper integration of the new extension with the existing structure to serve Primary Health Care Center and Basic Emergency Obstetric and Newborn Care (PHCC/BEmONC) facilities.

2. Adopted Design Codes & Standards

The structural analysis and design were conducted in accordance with the latest international engineering codes and guidelines:

- **Structural Concrete Design:** Developed based on the American Concrete Institute Code **ACI 318-19** (Building Code Requirements for Structural Concrete).
- **Design Loads:** Dead, live, and environmental loads were evaluated in accordance with **ASCE 7** (Minimum Design Loads for Buildings and Other Structures).
- **Technical Specifications:** Strict adherence to the quality and safety specifications approved by Médecins Sans Frontières (MSF).

3. Structural Material Specifications

Concrete Compressive Strength (f_c at 28 days):

Element Category	Compressive Strength (f_c)	Application / Description
Plain Concrete	20 MPa	Blinding layer under footings/foundations & Slab on Grade (SOG)

Reinforced Concrete (Footings)	30 MPa	High-strength concrete for footings to safely transfer loads to subgrade
-----------------------------------	--------	--

Reinforced Concrete (Superstructure)	35 MPa	High-strength concrete for neck columns, columns, ground beams, & slabs
---	--------	---

Steel Reinforcement (f_y):

Deformed high-yield steel bars conforming to ASTM A615 (Grade 60) with a minimum specified yield strength of $f_y = 420 \text{ MPa}$.

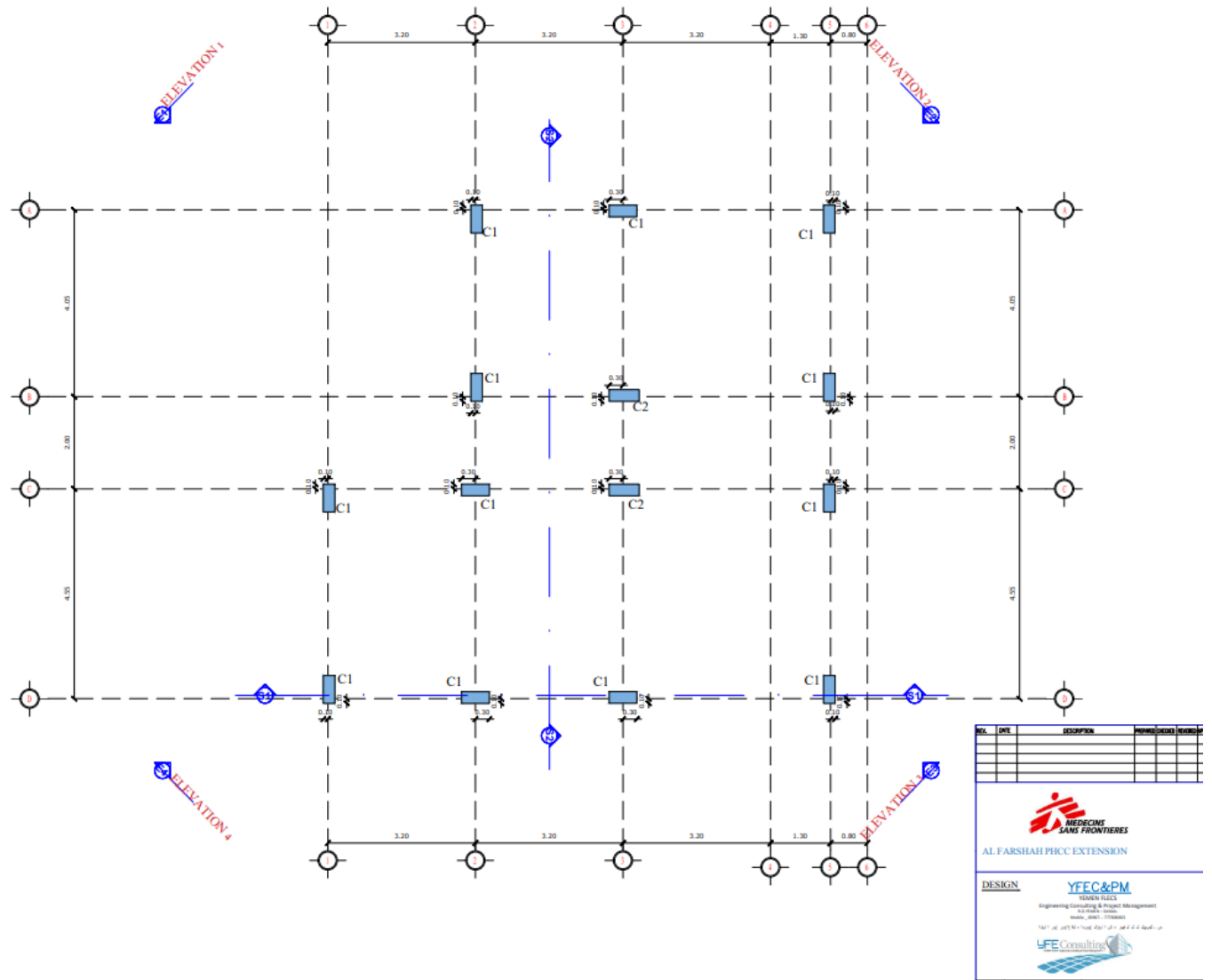
4. Loading & Structural Detailing Criteria

- **Live Load Distribution:** Imposed live loads were allocated based on medical occupancy types (corridors and public areas: 4.0 kN/m^2 , examination rooms and clinics: 2.5 kN/m^2).
- **Lap Splice Lengths:** Rebar lap splice lengths adhere strictly to the requirements of ACI 318-19, maintaining a minimum of $(50 \times \Phi)$.
- **Concrete Cover:** Concrete protection covers are determined based on exposure conditions (75 mm for foundations in contact with soil, 40 mm for columns and ground beams, and 25 mm for indoor slabs and structural elements).

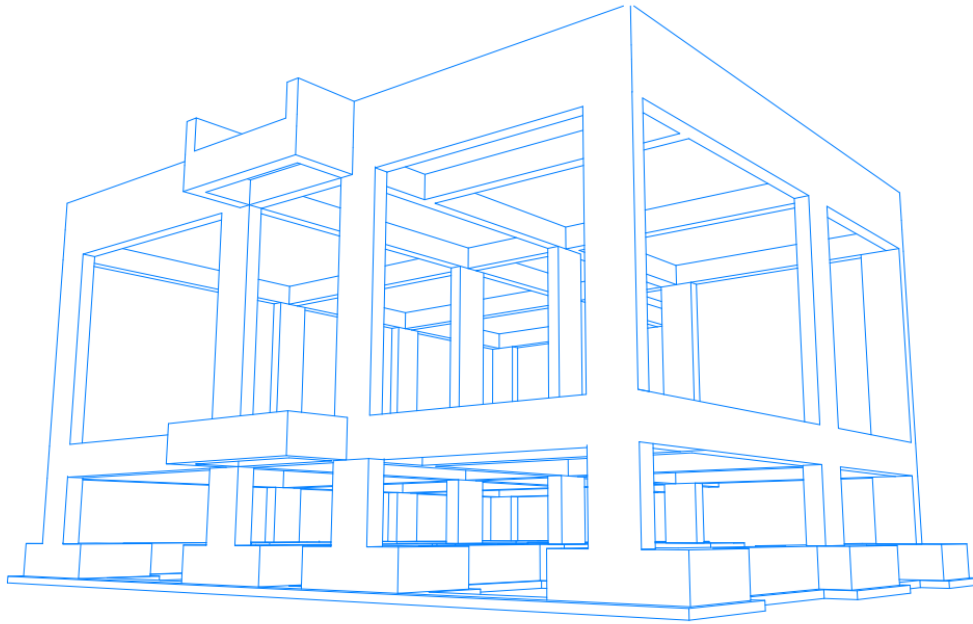
5. Structural Interface & Doweling with Existing Structure

The report outlines the engineered solutions for physically and structurally connecting the new extension to the existing Al Farshah facility:

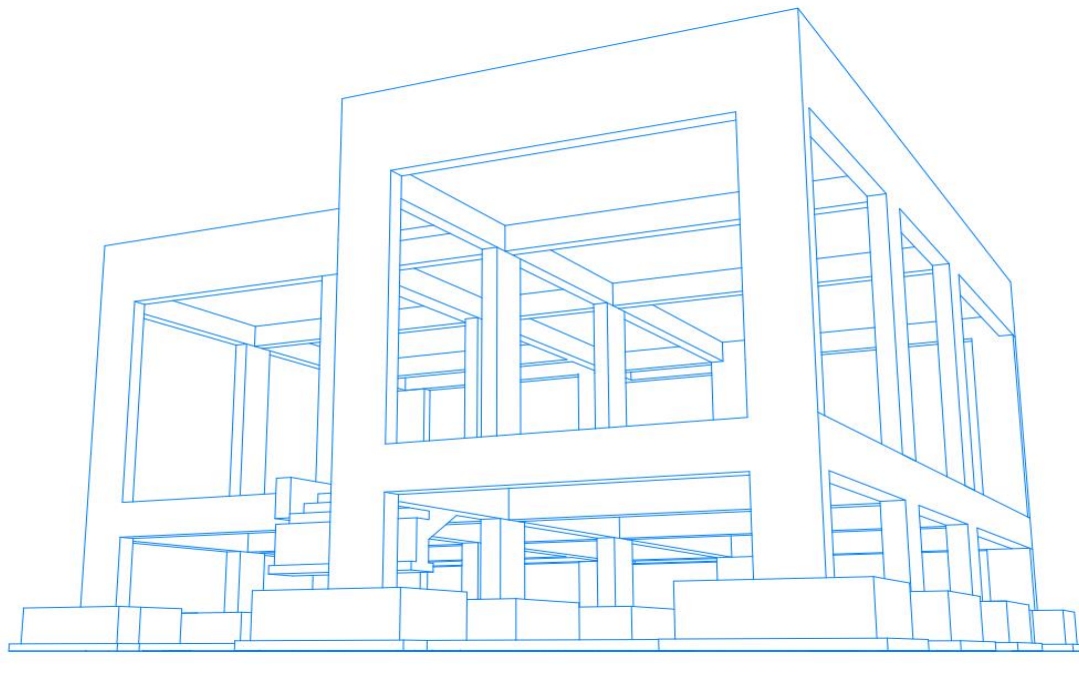
- Surface preparation and chipping of existing contact concrete faces to ensure proper bonding and structural continuity.
- Installation of chemical rebar dowels using approved epoxy resins (e.g., Hilti HIT-HY 200 or equivalent) according to calculated embedment lengths to transmit stresses safely and prevent differential settlement.



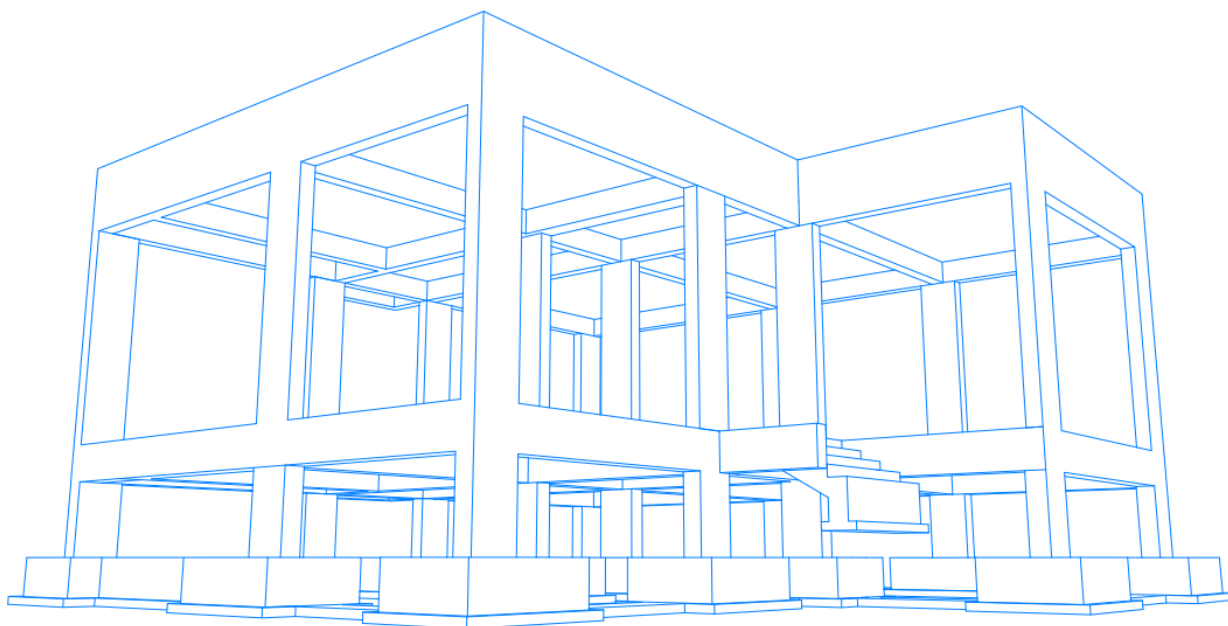
3-ELEVATION 3



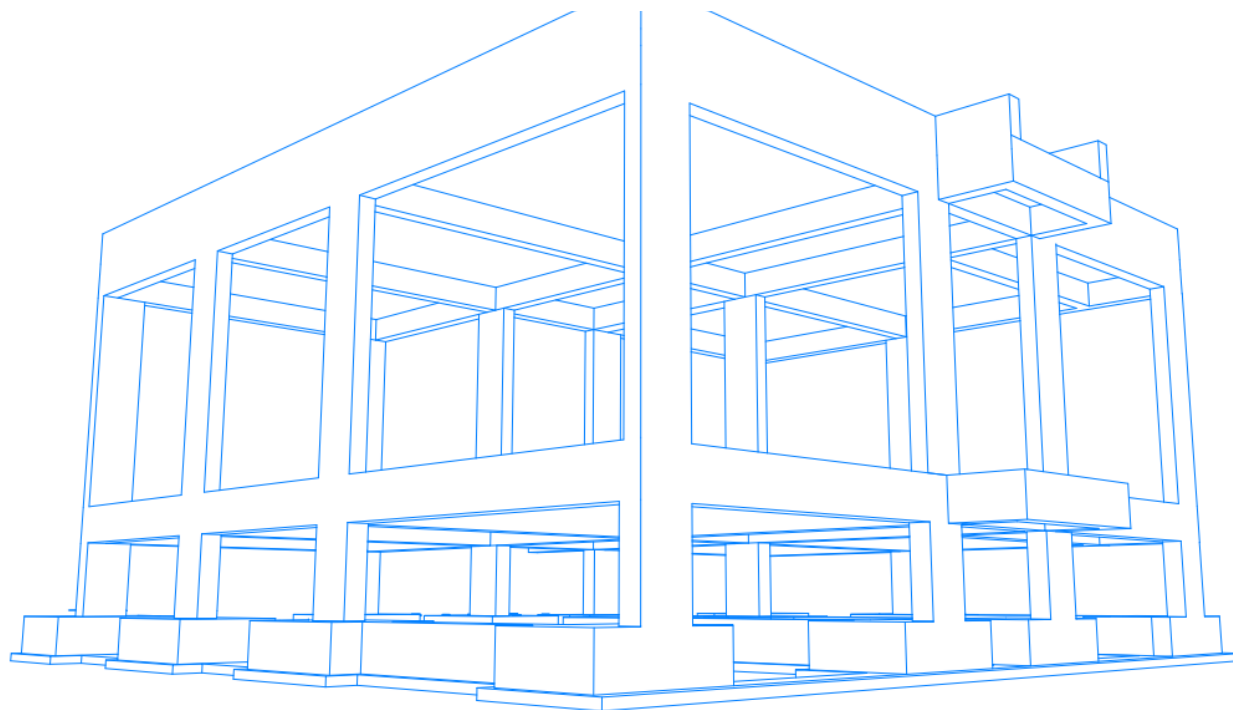
4-ELEVATION 4

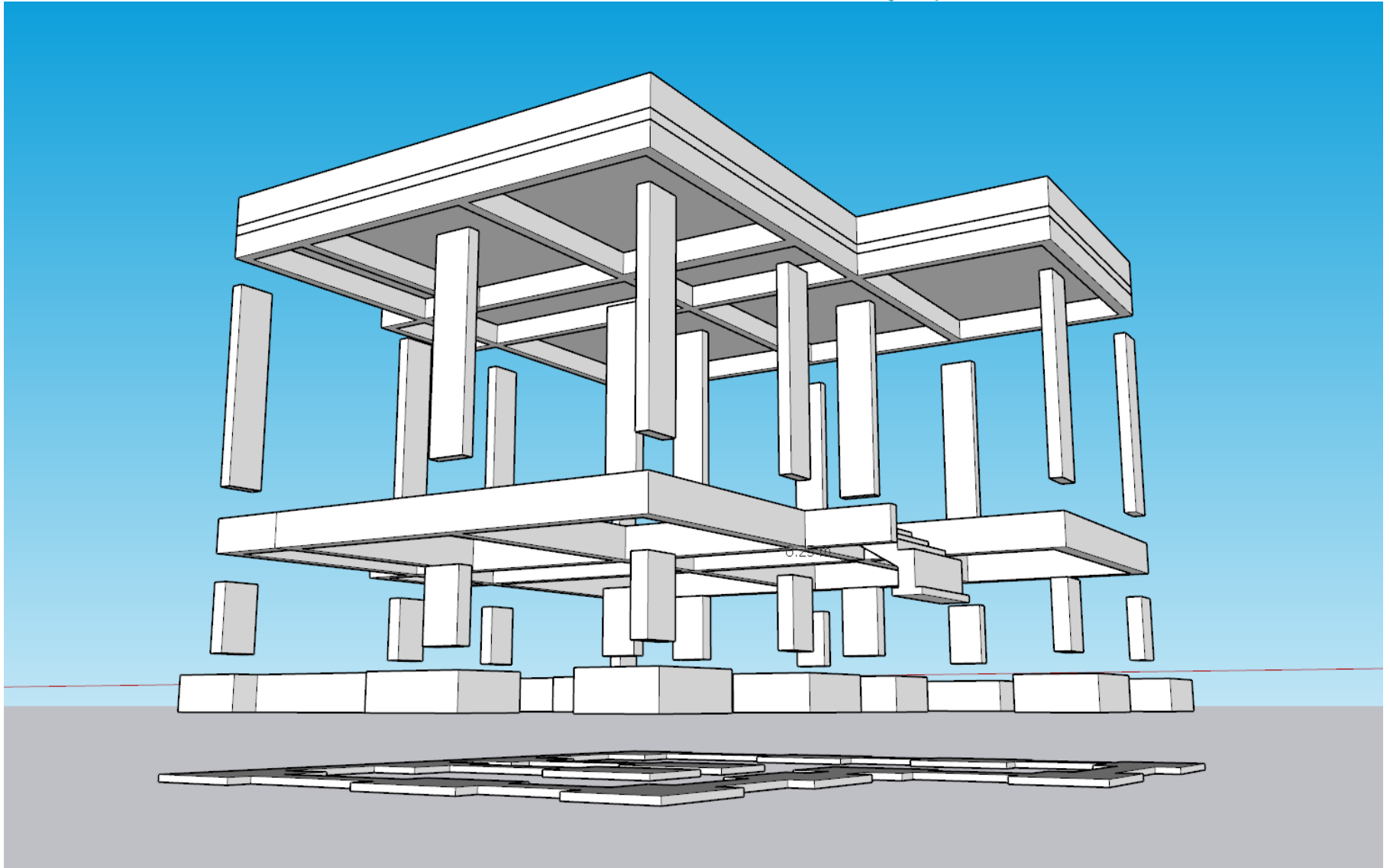


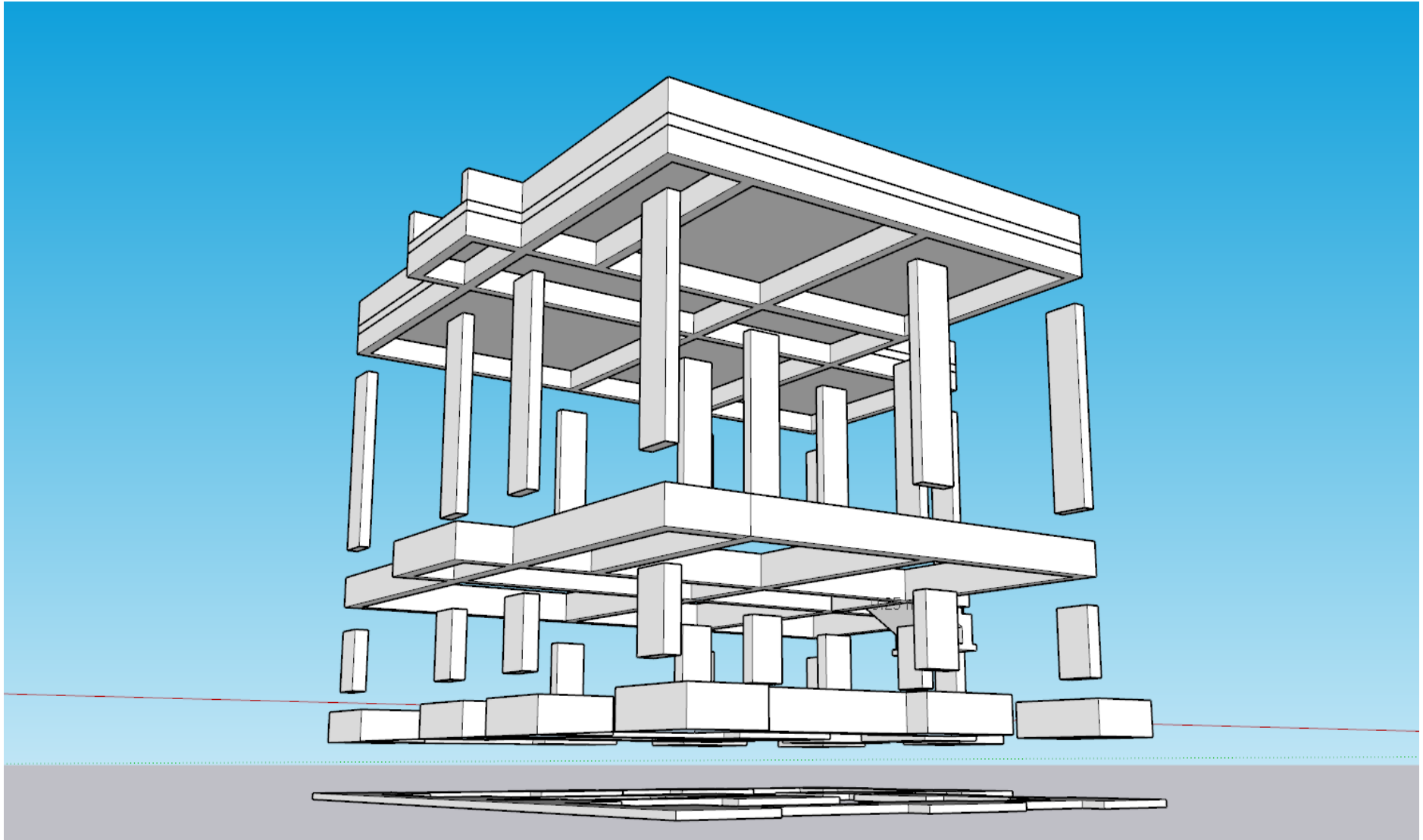
1- ELEVATION 1



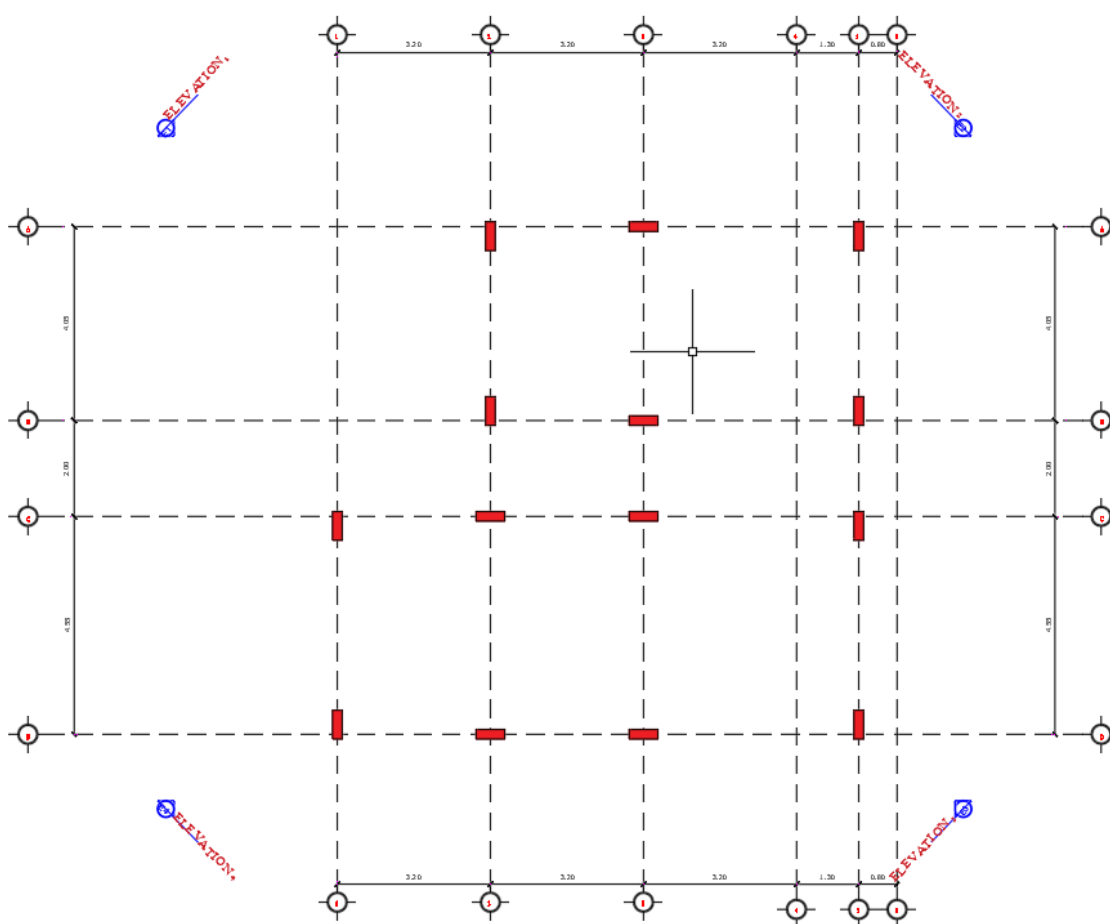
2-ELEVATION 2





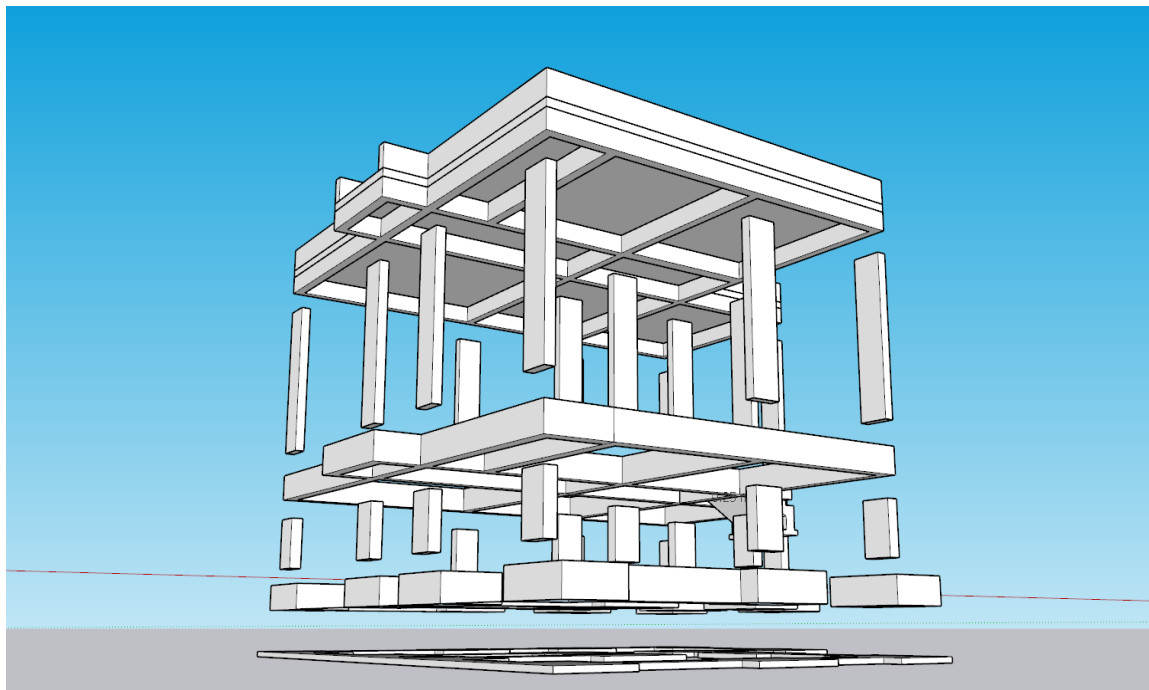


Structural Element Design



Structural Element Design

1- ROOF



Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis 1 | Beam Section: 20×50 cm | Factored Moment $M_u = 62.69 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis 1
- **Factored Bending Moment (M_u):** 62.69 kN·m ($62.69 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (62.69 \times 10^6) / (0.90 \times 200 \times 442^2) = 1.7827 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00444$
 - Required Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00444 \times 200 \times 442 = 392.4 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
 - **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (392.4 mm²) > $A_{s,min}$ (294.7 mm²), the applied moment governs, requiring $A_{s,req} = 392.4 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	2 ϕ 16 mm	402 mm ²	Exceeds $A_{s,req}$ (392.4 mm ²) by +2.9%. Fits easily in single layer.
Option 2 (Alternative)	3 ϕ 14 mm	462 mm ²	Exceeds $A_{s,req}$ (392.4 mm ²) by +18.2%. Excellent bar distribution.

As,req (Design Governing)	N/A	392.4 mm ²	Governed by applied factored moment Mu = 62.69 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis 1):

- Bottom Reinforcement (Tension): 2 ϕ 16 mm (As = 402 mm²) or 3 ϕ 14 mm (As = 462 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis 2 (Axis A–B) | Beam Section: 20×50 cm | Factored Moment $M_u = 63.12 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis 2 / Axis A–B
- **Factored Bending Moment (M_u):** 63.12 kN·m ($63.12 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (63.12 \times 10^6) / (0.90 \times 200 \times 442^2) = 1.7949 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00447$
 - Required Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00447 \times 200 \times 442 = 395.3 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
 - **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (395.3 mm²) > $A_{s,min}$ (294.7 mm²), the applied moment governs, requiring $A_{s,req} = 395.3 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	2 ϕ 16 mm	402 mm ²	Exceeds $A_{s,req}$ (395.3 mm ²) by +2.2%. Fits easily in a single layer.
Option 2 (Alternative)	3 ϕ 14 mm	462 mm ²	Exceeds $A_{s,req}$ (395.3 mm ²) by +17.4%. Excellent bar distribution.

As,req (Design Governing)	N/A	395.3 mm ²	Governed by applied factored moment Mu = 63.12 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis 2, Axis A–B):

- Bottom Reinforcement (Tension): 2 ϕ 16 mm (As = 402 mm²) or 3 ϕ 14 mm (As = 462 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis 2 (Axis D–C) | Beam Section: 20×50 cm | Factored Moment $M_u = 77.02 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis 2 / Axis D–C
- **Factored Bending Moment (M_u):** $77.02 \text{ kN}\cdot\text{m}$ ($77.02 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (77.02 \times 10^6) / (0.90 \times 200 \times 442^2) = 2.1902 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00552$
 - Required Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00552 \times 200 \times 442 = 487.6 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
 - **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (487.6 mm²) > $A_{s,min}$ (294.7 mm²), the applied moment governs, requiring $A_{s,req} = 487.6 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 16 mm	603 mm ²	Exceeds $A_{s,req}$ (487.6 mm ²) by +23.6%. Fits in single layer.
Option 2 (Alternative)	3 ϕ 18 mm	763 mm ²	Exceeds $A_{s,req}$ (487.6 mm ²) by +56.4%. Higher capacity.

As,req (Design Governing)	N/A	487.6 mm ²	Governed by applied factored moment Mu = 77.02 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis 2, Axis D–C):

- Bottom Reinforcement (Tension): 3 ϕ 16 mm (As = 603 mm²) or 3 ϕ 18 mm (As = 763 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis 3 (Axis 1–2) | Beam Section: 20×50 cm | Factored Moment $M_u = 69.98 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis 3 / Axis 1–2
- **Factored Bending Moment (M_u):** 69.98 kN·m ($69.98 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (69.98 \times 10^6) / (0.90 \times 200 \times 442^2) = 1.9900 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00498$
 - Required Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00498 \times 200 \times 442 = 440.5 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
 - **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (440.5 mm²) > $A_{s,min}$ (294.7 mm²), the applied moment governs, requiring $A_{s,req} = 440.5 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 14 mm	462 mm ²	Exceeds $A_{s,req}$ (440.5 mm ²) by +4.8%. Excellent single-layer fit.
Option 2 (Alternative)	3 ϕ 16 mm	603 mm ²	Exceeds $A_{s,req}$ (440.5 mm ²) by +36.9%. Provides additional strength.

As,req (Design Governing)	N/A	440.5 mm ²	Governed by applied factored moment Mu = 69.98 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis 3, Axis 1–2):

- Bottom Reinforcement (Tension): 3 ϕ 14 mm (As = 462 mm²) or 3 ϕ 16 mm (As = 603 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis 3 (Axis C–D) | Beam Section: 20×50 cm | Factored Moment $M_u = 85.45 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis 3 / Axis C–D
- **Factored Bending Moment (M_u):** $85.45 \text{ kN}\cdot\text{m}$ ($85.45 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (85.45 \times 10^6) / (0.90 \times 200 \times 442^2) = 2.4299 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00616$
 - Required Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00616 \times 200 \times 442 = 544.6 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
 - **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (544.6 mm²) > $A_{s,min}$ (294.7 mm²), the applied moment governs, requiring $A_{s,req} = 544.6 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 16 mm	603 mm ²	Exceeds $A_{s,req}$ (544.6 mm ²) by +10.5%. Fits in single layer.
Option 2 (Alternative)	3 ϕ 18 mm	763 mm ²	Exceeds $A_{s,req}$ (544.6 mm ²) by +39.8%. Provides additional capacity.

As,req (Design Governing)	N/A	544.6 mm ²	Governed by applied factored moment Mu = 85.45 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis 3, Axis C–D):

- Bottom Reinforcement (Tension): 3 ϕ 16 mm (As = 603 mm²) or 3 ϕ 18 mm (As = 763 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis 5 (Axis 1–2) | Beam Section: 20×50 cm | Factored Moment $M_u = 55.37 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis 5 / Axis 1–2
- **Factored Bending Moment (M_u):** 55.37 kN·m ($55.37 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (55.37 \times 10^6) / (0.90 \times 200 \times 442^2) = 1.5746 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00390$
 - Required Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00390 \times 200 \times 442 = 344.7 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
 - **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (344.7 mm²) > $A_{s,min}$ (294.7 mm²), the applied moment governs, requiring $A_{s,req} = 344.7 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 14 mm	462 mm ²	Exceeds $A_{s,req}$ (344.7 mm ²) by +33.8%. Excellent single-layer fit.
Option 2 (Economical)	3 ϕ 12 mm	339 mm ²	Under-reinforced relative to $A_{s,calc}$ (344.7 mm ²). Requires 3 ϕ 14 mm.

As,req (Design Governing)	N/A	344.7 mm ²	Governed by applied factored moment Mu = 55.37 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis 5, Axis 1–2):

- Bottom Reinforcement (Tension): 3 ϕ 14 mm (As = 462 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis 5 (Axis C–D) | Beam Section: 20×50 cm | Factored Moment $M_u = 67.6 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis 5 / Axis C–D
- **Factored Bending Moment (M_u):** 67.60 kN·m ($67.60 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (67.60 \times 10^6) / (0.90 \times 200 \times 442^2) = 1.9223 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00481$
 - Required Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00481 \times 200 \times 442 = 424.8 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
 - **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (424.8 mm²) > $A_{s,min}$ (294.7 mm²), the applied moment governs, requiring $A_{s,req} = 424.8 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 14 mm	462 mm ²	Exceeds $A_{s,req}$ (424.8 mm ²) by +8.8%. Excellent single-layer fit.
Option 2 (Alternative)	3 ϕ 16 mm	603 mm ²	Exceeds $A_{s,req}$ (424.8 mm ²) by +42.1%. Provides additional strength.

As,req (Design Governing)	N/A	424.8 mm ²	Governed by applied factored moment Mu = 67.60 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis 5, Axis C–D):

- Bottom Reinforcement (Tension): 3 ϕ 14 mm (As = 462 mm²) or 3 ϕ 16 mm (As = 603 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis A (Axis 3–2) | Beam Section: 20×50 cm | Factored Moment $M_u = 61.064 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis A / Axis 3–2
- **Factored Bending Moment (M_u):** 61.064 kN·m ($61.064 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (61.064 \times 10^6) / (0.90 \times 200 \times 442^2) = 1.7365 \text{ MPa}$
- Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00432$
- Required Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00432 \times 200 \times 442 = 381.8 \text{ mm}^2$
- Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
- Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (381.8 mm²) > $A_{s,min}$ (294.7 mm²), the applied moment governs, requiring $A_{s,req} = 381.8 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 14 mm	462 mm ²	Exceeds $A_{s,req}$ (381.8 mm ²) by +21.0%. Excellent single-layer fit.
Option 2 (Alternative)	3 ϕ 16 mm	603 mm ²	Exceeds $A_{s,req}$ (381.8 mm ²) by +58.1%. Provides

extra capacity.

As,req (Design Governing)	N/A	381.8 mm ²	Governed by applied factored moment Mu = 61.064 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis 5, Axis 3–2):

- Bottom Reinforcement (Tension): 3 ϕ 14 mm (As = 462 mm²) or 3 ϕ 16 mm (As = 603 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis A (Axis 3–5) | Beam Section: 20×50 cm | Factored Moment $M_u = 62.76 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis A / Axis 3–5
- **Factored Bending Moment (M_u):** 62.76 kN·m ($62.76 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (62.76 \times 10^6) / (0.90 \times 200 \times 442^2) = 1.7847 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00444$
 - Required Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00444 \times 200 \times 442 = 392.9 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
 - **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (392.9 mm²) > $A_{s,min}$ (294.7 mm²), the applied moment governs, requiring $A_{s,req} = 392.9 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 14 mm	462 mm ²	Exceeds $A_{s,req}$ (392.9 mm ²) by +17.2%. Excellent single-layer fit.
Option 2 (Alternative)	3 ϕ 16 mm	603 mm ²	Exceeds $A_{s,req}$ (392.9 mm ²) by +53.1%. Provides extra strength.

As,req (Design Governing)	N/A	392.9 mm ²	Governed by applied factored moment Mu = 62.76 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis A, Axis 3–5):

- Bottom Reinforcement (Tension): 3 ϕ 14 mm (As = 462 mm²) or 3 ϕ 16 mm (As = 603 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis B (Axis 3–2) | Beam Section: 20×50 cm | Factored Moment $M_u = 22.479$ kN·m

1. Design Parameters & Geometric Data

- Grid Location:** Axis B / Axis 3–2
- Factored Bending Moment (M_u):** 22.479 kN·m (22.479×10^6 N·mm)
- Section Width (b):** 200 mm (20 cm)
- Section Height (h):** 500 mm (50 cm)
- Clear Concrete Cover:** 40 mm
- Stirrup Diameter (ϕ_s):** 10 mm
- Assumed Main Bar Diameter (ϕ_b):** 16 mm
- Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0$ mm
- Concrete Compressive Strength (f'_c):** 25 MPa
- Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (22.479 \times 10^6) / (0.90 \times 200 \times 442^2) = 0.6392$ MPa
- Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00155$
- Calculated Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00155 \times 200 \times 442 = 136.6$ mm²
- Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1$ mm²
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7$ mm²
- Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
- Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (136.6 mm²) < $A_{s,min}$ (294.7 mm²), ACI 318-19 Section 9.6.1.2 governs, requiring $A_{s,req} = 294.7$ mm².

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 12 mm	339 mm ²	Exceeds $A_{s,min}$ (294.7 mm ²) by +15.1%. Excellent single-layer placement.
Option 2 (Alternative)	2 ϕ 14 mm	308 mm ²	Exceeds $A_{s,min}$ (294.7 mm ²) by +4.5%. Compliant and

highly economical.

As,min (ACI Governing)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 minimum requirement.
As,calc (Applied Moment)	N/A	136.6 mm ²	Calculated required area from Mu = 22.479 kN·m.

4. Summary of Detailing Requirements (Axis B, Axis 3–2):

- Bottom Reinforcement (Tension): 3 ϕ 12 mm (As = 339 mm²) or 2 ϕ 14 mm (As = 308 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis B (Axis 3–5) | Beam Section: 20×50 cm | Factored Moment $M_u = 54.58 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis B / Axis 3–5
- **Factored Bending Moment (M_u):** $54.58 \text{ kN}\cdot\text{m}$ ($54.58 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (54.58 \times 10^6) / (0.90 \times 200 \times 442^2) = 1.5521 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00384$
 - Required Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00384 \times 200 \times 442 = 339.6 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
 - **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (339.6 mm²) > $A_{s,min}$ (294.7 mm²), the applied moment governs, requiring $A_{s,req} = 339.6 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 14 mm	462 mm ²	Exceeds $A_{s,req}$ (339.6 mm ²) by +36.0%. Excellent single-layer fit.
Option 2 (Economical)	3 ϕ 12 mm	339 mm ²	Under-reinforced relative to $A_{s,calc}$ (339.6 mm ²). Requires 3 ϕ 14 mm.

As,req (Design Governing)	N/A	339.6 mm ²	Governed by applied factored moment Mu = 54.58 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis B, Axis 3–5):

- Bottom Reinforcement (Tension): 3 ϕ 14 mm (As = 462 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis C (Axis 1–2) | Beam Section: 20×50 cm | Factored Moment $M_u = 38.28 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis C / Axis 1–2
- **Factored Bending Moment (M_u):** $38.28 \text{ kN}\cdot\text{m}$ ($38.28 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (38.28 \times 10^6) / (0.90 \times 200 \times 442^2) = 1.0886 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00266$
 - Calculated Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00266 \times 200 \times 442 = 235.3 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
- **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (235.3 mm²) < $A_{s,min}$ (294.7 mm²), ACI 318-19 Section 9.6.1.2 governs, requiring $A_{s,req} = 294.7 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 12 mm	339 mm ²	Exceeds $A_{s,min}$ (294.7 mm ²) by +15.1%. Excellent single-layer placement.
Option 2 (Alternative)	2 ϕ 14 mm	308 mm ²	Exceeds $A_{s,min}$ (294.7 mm ²) by +4.5%. Compliant and highly economical.

As,min (ACI Governing)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 minimum requirement.
As,calc (Applied Moment)	N/A	235.3 mm ²	Calculated required area from Mu = 38.28 kN·m.

4. Summary of Detailing Requirements (Axis C, Axis 1–2):

- Bottom Reinforcement (Tension): 3 ϕ 12 mm (As = 339 mm²) or 2 ϕ 14 mm (As = 308 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis C (Axis 2–3) | Beam Section: 20×50 cm | Factored Moment $M_u = 11.287 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis C / Axis 2–3
- **Factored Bending Moment (M_u):** 11.287 kN·m ($11.287 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (11.287 \times 10^6) / (0.90 \times 200 \times 442^2) = 0.3210 \text{ MPa}$
- Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.000770$
- Calculated Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.000770 \times 200 \times 442 = 68.1 \text{ mm}^2$
- Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
- Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (68.1 mm²) < $A_{s,min}$ (294.7 mm²), ACI 318-19 Section 9.6.1.2 governs, requiring $A_{s,req} = 294.7 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 12 mm	339 mm ²	Exceeds $A_{s,min}$ (294.7 mm ²) by +15.1%. Excellent single-layer placement.
Option 2 (Alternative)	2 ϕ 14 mm	308 mm ²	Exceeds $A_{s,min}$ (294.7 mm ²) by +4.5%. Compliant and

highly economical.

As,min (ACI Governing)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 minimum requirement.
As,calc (Applied Moment)	N/A	68.1 mm ²	Calculated required area from Mu = 11.287 kN·m.

4. Summary of Detailing Requirements (Axis C, Axis 2–3):

- Bottom Reinforcement (Tension): 3 ϕ 12 mm (As = 339 mm²) or 2 ϕ 14 mm (As = 308 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis C (Axis 2–3) | Beam Section: 20×50 cm | Factored Moment $M_u = 11.287 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis C / Axis 2–3
- **Factored Bending Moment (M_u):** 11.287 kN·m ($11.287 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

1. **Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (11.287 \times 10^6) / (0.90 \times 200 \times 442^2) = 0.3210 \text{ MPa}$
 2. **Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.000770$
 3. **Calculated Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.000770 \times 200 \times 442 = 68.1 \text{ mm}^2$
 4. **Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
- **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (68.1 mm²) < $A_{s,min}$ (294.7 mm²), ACI 318-19 Section 9.6.1.2 governs, requiring $A_{s,req} = 294.7 \text{ mm}^2$.

3. Reinforcement Schedule & Options

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 12 mm	339 mm ²	Exceeds $A_{s,min}$ (294.7 mm ²) by +15.1%. Excellent single-layer placement.
Option 2 (Alternative)	2 ϕ 14 mm	308 mm ²	Exceeds $A_{s,min}$ (294.7 mm ²) by +4.5%. Compliant and

highly economical.

As,min (ACI Governing)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 minimum requirement.
As,calc (Applied Moment)	N/A	68.1 mm ²	Calculated required area from Mu = 11.287 kN·m.

4. Summary of Detailing Requirements (Axis C, Axis 2–3):

- Bottom Reinforcement (Tension): 3 ϕ 12 mm (As = 339 mm²) or 2 ϕ 14 mm (As = 308 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis D (Axis 1–2) | Beam Section: 20×50 cm | Factored Moment $M_u = 38.82 \text{ kN}\cdot\text{m}$

1. Design Parameters & Input Data

- **Grid Reference:** Axis D / Axis 1–2
- **Factored Bending Moment (M_u):** $38.82 \text{ kN}\cdot\text{m}$ ($38.82 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Strength (f'_c):** 25 MPa
- **Steel Yield Strength (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Analysis & Steel Area Calculation

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (38.82 \times 10^6) / (0.90 \times 200 \times 442^2) = 1.1039 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00270$
 - Required Calculated Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00270 \times 200 \times 442 = 238.7 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
- **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (238.7 mm²) > $A_{s,min}$ (294.7 mm²), the governing required steel area is $A_{s,req} = 238.7 \text{ mm}^2$.

3. Reinforcement Schedule & Comparison

Design Option	Rebar Selection	Provided Area (A_s)	Structural Remarks & Efficiency
Option 1 (Optimal Choice)	2 ϕ 16 mm	402 mm ²	Meets $A_{s,req}$ (238.7 mm ²) with +25.3% margin. Single layer fit.
Option 2 (Alternative)	3 ϕ 14 mm	462 mm ²	Meets $A_{s,req}$ (238.7 mm ²) with +43.9% margin. Excellent ductility.

As,req (Design Governing)	N/A	238.7 mm ²	Governed by applied moment Mu = 38.82 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis D, Axis 1–2):

- Bottom Reinforcement (Tension): 2 ϕ 16 mm (As = 402 mm²) or 3 ϕ 14 mm (As = 462 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 150 mm c/c near supports / @ 200 mm c/c at mid-span (per ACI 318-19 detailing standards)

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis D (Axis 2–3) | Beam Section: 20×50 cm | Factored Moment $M_u = 10 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Reference:** Axis D / Axis 2–3
- **Factored Bending Moment (M_u):** $10 \text{ kN}\cdot\text{m}$ ($10 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Assumed Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Steel Yield Strength (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength & Minimum Reinforcement Calculations

1. **Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (10 \times 10^6) / (0.90 \times 200 \times 442^2) = 0.285 \text{ MPa}$

2. **Reinforcement Ratio (ρ):** $\rho = 0.00069$

3. **Theoretical Steel Area Required ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00069 \times 200 \times 442 = 61 \text{ mm}^2$

4. **Minimum Flexural Reinforcement (ACI 318-19 Sec. 9.6.1.2):**

- $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263 \text{ mm}^2$

- $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 295 \text{ mm}^2$

• **Governing Minimum Reinforcement Area:** $A_{s,min} = 295 \text{ mm}^2$

• **Code Provision (Sec. 9.6.1.3):** If $A_{s,min}$ exceeds $A_{s,calc}$ by more than 33%, the required steel area may be reduced to $(4/3) \times A_{s,calc} = 81.3 \text{ mm}^2$. However, providing $A_{s,min} = 295 \text{ mm}^2$ is recommended for crack control and structural integrity.

3. Reinforcement Schedule & Detailing Recommendations

Design Parameter / Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal Choice)	2 ϕ 14 mm	308 mm ²	Meets $A_{s,min}$ (295 mm ²) with +4.4% margin. Most economical.
Option 2 (Standard Choice)	2 ϕ 16 mm	402 mm ²	Meets $A_{s,min}$ with +36.2% margin. Recommended if ϕ 14

mm is unavailable.

As,min (ACI Requirement)	N/A	295 mm ²	Governed by ACI 318-19 Section 9.6.1.2.
As,calc (Theoretical)	N/A	61 mm ²	Governed by small applied moment (Mu = 10 kN·m).

4. Summary of Detailing Requirements (Axis D, Axis 2–3):

- Bottom Reinforcement (Tension): 2 ϕ 14 mm (or 2 ϕ 16 mm)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 200 mm c/c (Nominal shear reinforcement per ACI 318-19 Table 9.7.6.2.2)

Reinforced Concrete Beam Design (ACI 318-19)

Location: Axis D (Axis 3–5) | Section: 20×50 cm | Factored Moment $M_u = 73.75 \text{ kN}\cdot\text{m}$

1. Design Parameters & Geometric Data

- **Grid Location:** Axis D / Axis 3–5
- **Factored Bending Moment (M_u):** 73.75 kN·m ($73.75 \times 10^6 \text{ N}\cdot\text{mm}$)
- **Section Width (b):** 200 mm (20 cm)
- **Section Height (h):** 500 mm (50 cm)
- **Clear Concrete Cover:** 40 mm
- **Stirrup Diameter (ϕ_s):** 10 mm
- **Main Bar Diameter (ϕ_b):** 16 mm
- **Effective Depth (d):** $d = 500 - 40 - 10 - (16 / 2) = 442.0 \text{ mm}$
- **Concrete Compressive Strength (f'_c):** 25 MPa
- **Yield Strength of Steel (f_y):** 420 MPa (Grade 60)
- **Strength Reduction Factor (ϕ):** 0.90 (Tension-controlled)

2. Flexural Strength Calculations & Reinforcement Area

- Nominal Resistance Factor (R_n):** $R_n = M_u / (\phi \cdot b \cdot d^2) = (73.75 \times 10^6) / (0.90 \times 200 \times 442^2) = 2.0972 \text{ MPa}$
 - Reinforcement Ratio (ρ):** $\rho = (0.85 \cdot f'_c / f_y) \cdot [1 - \sqrt{1 - 2R_n / (0.85 \cdot f'_c)}] = 0.00527$
 - Required Tension Steel Area ($A_{s,calc}$):** $A_{s,calc} = \rho \cdot b \cdot d = 0.00527 \times 200 \times 442 = 465.7 \text{ mm}^2$
 - Minimum Flexural Reinforcement Check (ACI 318-19 Sec 9.6.1.2):**
 - $A_{s,min,1} = (0.25 \times \sqrt{f'_c} / f_y) \cdot b \cdot d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$
 - $A_{s,min,2} = (1.4 / f_y) \cdot b \cdot d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$
- **Minimum Steel Area ($A_{s,min}$):** 294.7 mm²
 - **Governing Required Steel Area ($A_{s,req}$):** Since $A_{s,calc}$ (465.7 mm²) > $A_{s,min}$ (294.7 mm²), the applied moment governs, requiring $A_{s,req} = 465.7 \text{ mm}^2$.

3. Reinforcement Options & Schedule

Design Option	Rebar Selection	Provided Area (A_s)	Compliance & Structural Remarks
Option 1 (Optimal)	3 ϕ 16 mm	603 mm ²	Exceeds $A_{s,req}$ (465.7 mm ²) by +23.6%. Fits in single layer.
Option 2 (Alternative)	3 ϕ 18 mm	763 mm ²	Exceeds $A_{s,req}$ (465.7 mm ²) by +56.2%. Higher capacity.

As,req (Design Governing)	N/A	465.7 mm ²	Governed by applied moment Mu = 73.75 kN·m.
As,min (ACI Minimum)	N/A	294.7 mm ²	ACI 318-19 Section 9.6.1.2 requirement.

4. Summary of Detailing Requirements (Axis D, Axis 3–5):

- Bottom Reinforcement (Tension): 3 ϕ 16 mm (As = 603 mm²) or 3 ϕ 18 mm (As = 763 mm²)
- Top Reinforcement (Hanger Bars): 2 ϕ 12 mm
- Stirrup Reinforcement: ϕ 10 mm @ 125 mm c/c near supports / @ 175 mm c/c at mid-span

REINFORCED CONCRETE BEAM DESIGN REPORT

Compliance Standard: ACI 318-19 | Location: Axis C (Axes 3–5)

1. Design Inputs & Parameters

Parameter	Design Value
Member Location	Axis C — Axes 3–5
Factored Ultimate Moment (Mu)	64.80 kN·m
Section Width (b)	20 cm (200 mm)
Section Height (h)	50 cm (500 mm)
Concrete Compressive Strength (f'c)	25 MPa (Standard Structural Concrete)
Steel Yield Strength (fy)	420 MPa (Grade 60)
Clear Cover (cc)	40 mm (ACI 318 exterior/interior exposure)
Assumed Stirrup Diameter (d_s)	10 mm
Assumed Main Rebar Diameter (d_b)	16 mm
Effective Depth (d)	$h - cc - d_s - d_b/2 = 500 - 40 - 10 - 8 = 442 \text{ mm}$

2. Step-by-Step Flexural Analysis & Design (ACI 318)

Step 2.1: Stress Block Factors & Reduction Factor

- For $f'c = 25 \text{ MPa}$ ($\leq 28 \text{ MPa}$), Whitney stress block factor $\beta_1 = 0.85$.
- Initial assumption for strength reduction factor for tension-controlled section: $\phi = 0.90$.

Step 2.2: Nominal Moment Capacity Required

$Mn_{req} = Mu / \phi = 64.80 \text{ kN}\cdot\text{m} / 0.90 = 72.00 \text{ kN}\cdot\text{m} = 72.00 \times 10^6 \text{ N}\cdot\text{mm}$

Step 2.3: Depth of Equivalent Stress Block (a)

From quadratic flexural formula: $M_n = A_s \cdot f_y \cdot (d - a/2)$ where $a = (A_s \cdot f_y) / (0.85 \cdot f'_c \cdot b)$.

Substituting gives: $M_n = (0.85 \cdot f'_c \cdot b \cdot a) \cdot (d - a/2)$

$$72.00 \times 10^6 = 0.85 \times 25 \times 200 \times a \times (442 - 0.5 a)$$

$$72.00 \times 10^6 = 4250 a (442 - 0.5 a) = 1,878,500 a - 2125 a^2$$

Rearranging into standard quadratic form: **$2125 a^2 - 1,878,500 a + 72,000,000 = 0$**

Solving quadratic equation: **$a = 40.23 \text{ mm}$**

Step 2.4: Neutral Axis Depth (c) & Strain Verification

$$c = a / \beta_1 = 40.23 \text{ mm} / 0.85 = \mathbf{47.33 \text{ mm}}$$

Net tensile strain in extreme tension steel (ϵ_t):

$$\epsilon_t = 0.003 \times [(d - c) / c] = 0.003 \times [(442 - 47.33) / 47.33] = \mathbf{0.0250 (2.50\%)}$$

Validation: Since $\epsilon_t = 0.0250 \geq 0.005$, the section is strictly **TENSION-CONTROLLED**. Thus, $\phi = \mathbf{0.90}$ assumption is fully valid.

Step 2.5: Required Tensile Reinforcement Area (A_s)

$$A_{s_req} = (0.85 \cdot f'_c \cdot b \cdot a) / f_y = (0.85 \times 25 \times 200 \times 40.23) / 420 = \mathbf{407.1 \text{ mm}^2}$$

Step 2.6: ACI 318 Minimum & Maximum Reinforcement Limits

ACI 318 minimum reinforcement requirement:

$$\bullet A_{s_min,1} = (0.25 \times \sqrt{f'_c} / f_y) \times b \times d = (0.25 \times \sqrt{25} / 420) \times 200 \times 442 = 263.1 \text{ mm}^2$$

$$\bullet A_{s_min,2} = (1.4 / f_y) \times b \times d = (1.4 / 420) \times 200 \times 442 = 294.7 \text{ mm}^2$$

$$A_{s_min} = \max(263.1, 294.7) = \mathbf{294.7 \text{ mm}^2}$$

Check: $A_{s_req} (407.1 \text{ mm}^2) > A_{s_min} (294.7 \text{ mm}^2) \rightarrow \mathbf{OK (Minimum Reinforcement Satisfied)}$

ACI 318 Maximum Reinforcement Limit ($\epsilon_t \geq 0.004$):

$$c_max = (0.003 / (0.003 + 0.004)) \times d = (3/7) \times 442 = 189.4 \text{ mm}$$

$$a_max = 0.85 \times 189.4 = 161.0 \text{ mm}$$

$$A_{s_max} = (0.85 \times 25 \times 200 \times 161.0) / 420 = \mathbf{1630.0 \text{ mm}^2}$$

Check: $A_{s_req} (407.1 \text{ mm}^2) \leq A_{s_max} (1630.0 \text{ mm}^2) \rightarrow \mathbf{OK (Singly Reinforced Section Valid)}$

3. Reinforcement Selection & Detailing

Selected Rebar Layout: 3 Φ 14 mm bars

$$\bullet \text{ Provided Steel Area } (A_{s_provided}): 3 \times (\pi/4 \times 14^2) = 3 \times 153.94 \text{ mm}^2 = \mathbf{461.8 \text{ mm}^2}$$

$\bullet$ Capacity Check: $A_{s_provided} (461.8 \text{ mm}^2) > A_{s_req} (407.1 \text{ mm}^2) \rightarrow \mathbf{SAFE (113.4\% Capacity Provided)}$

DESIGN SUMMARY & CAPACITY VERIFICATION

- Member: Beam Axis C (Axes 3–5)
- Dimensions: $b = 200 \text{ mm}$, $h = 500 \text{ mm}$ ($d = 443 \text{ mm}$ adjusted for $\Phi 14$)

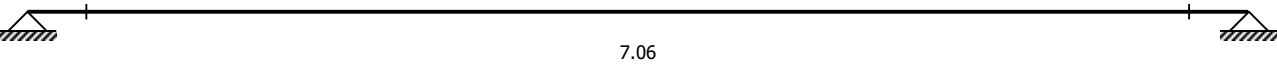
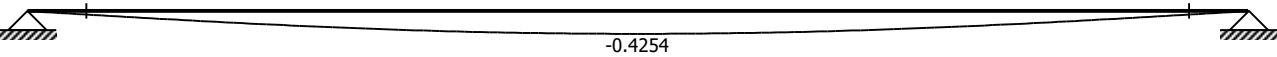
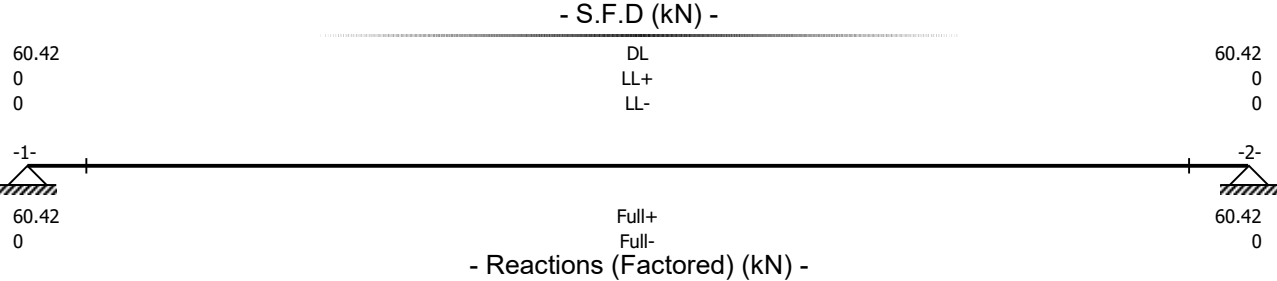
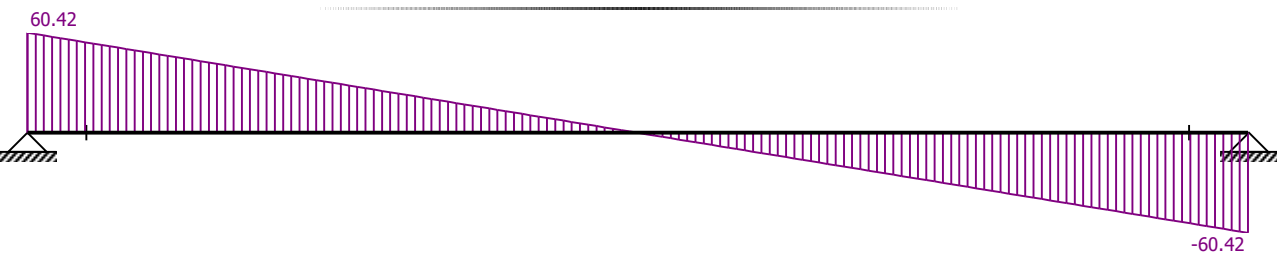
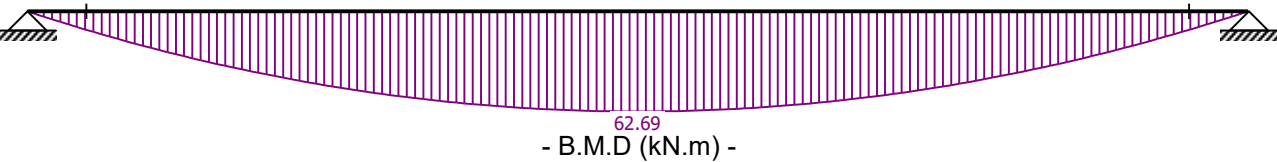
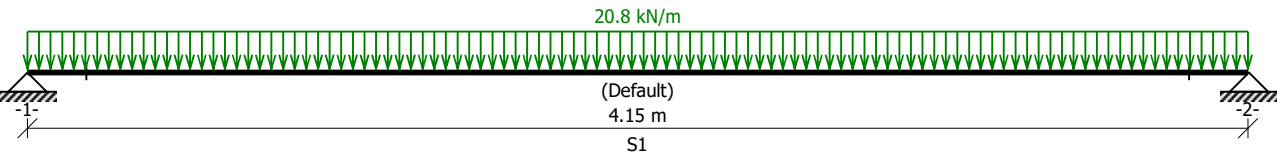
- Design Factored Moment (M_u): 64.80 kN·m
- Calculated Nominal Capacity (ϕM_n): 73.18 kN·m
- Safety Margin / Ratio ($M_u / \phi M_n$): 0.885 (< 1.00 - SAFE)
- Main Reinforcement: 3 Φ 14 mm ($A_s = 461.8 \text{ mm}^2$ in 1 layer)
- Top Hanger Reinforcement: 2 Φ 12 mm (Constructability & Stirrup Support)
- Shear Stirrups: Φ 10 mm @ 150 mm c/c (Nominal Shear Layout)

4. Summary of Results Table

Design Parameter	Value	ACI 318 Standard Reference / Note
Design Moment (M_u)	64.80 kN·m	ACI 318 Load Combinations
Effective Depth (d)	443 mm	$h = 500 \text{ mm}$, cover = 40 mm
Required Steel (A_{s_req})	407.1 mm ²	Calculated from flexure
Minimum Steel (A_{s_min})	294.7 mm ²	ACI 318-19 Section 9.6.1.2
Provided Steel (A_{s_prov})	461.8 mm ²	3 Φ 14 mm bottom bars
Factored Capacity (ϕM_n)	73.18 kN·m	$\phi = 0.90$ (Tension Controlled)
Design Status	PASS / SAFE	$M_u / \phi M_n = 88.5\%$

Beam Name : Beam 1 , Count : 1 , Force's Units : kN , kN/m , kN.m , (Fy=4000, Fey=2400, F'c=180 kgf/cm²)

Load Case Is Envelope , , Ultimate Strength , U= 1.4 DL + 1.7 LL ,



Moments

Beam 1 (kN.m)

Span	Mleft+	Mleft-	Mright+	Mright-	Mmax+	X1	Mmax-	X2
1	0	0	0	0	62.69	2.075	0	4.15

Shear Forces

Beam 1 (kN)

Span	Qleft+	Qleft-	Qright+	Qright-	Qmax+	X1	Qmax-	X2
1	60.42	0	0	-60.42	60.42	0	-60.42	4.15

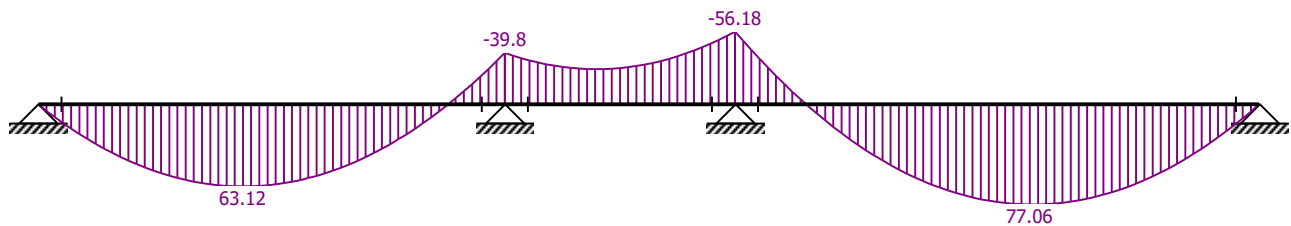
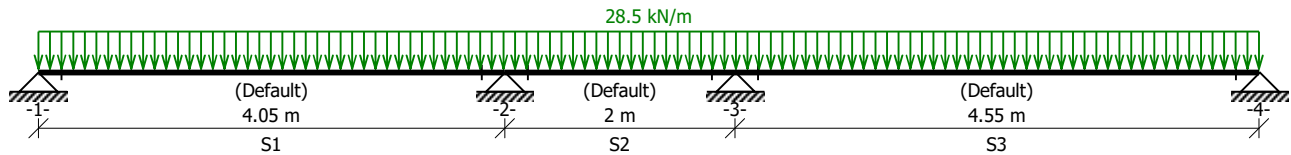
Reactions

Beam 1 (kN) :

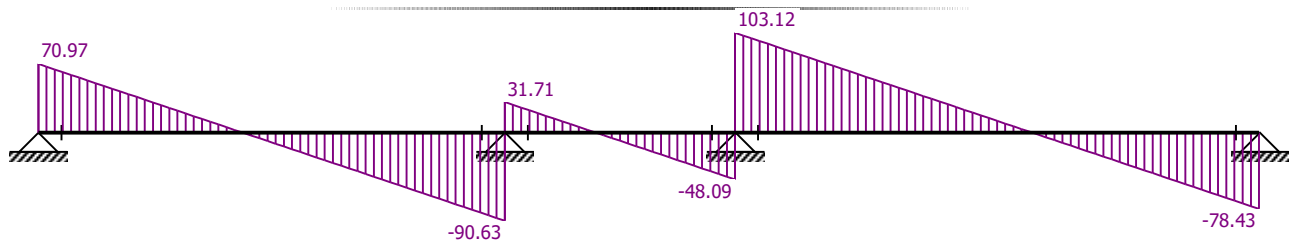
Support	Name	DL	LL+	LL-	Def	Full+	Full-
1		60.42	0	0	0	60.42	0
2		60.42	0	0	0	60.42	0

Beam Name : Beam 1 , Count : 1 , Force's Units : kN , kN/m , kN.m , (Fy=4000, Fey=2400, F'c=180 kgf/cm²)

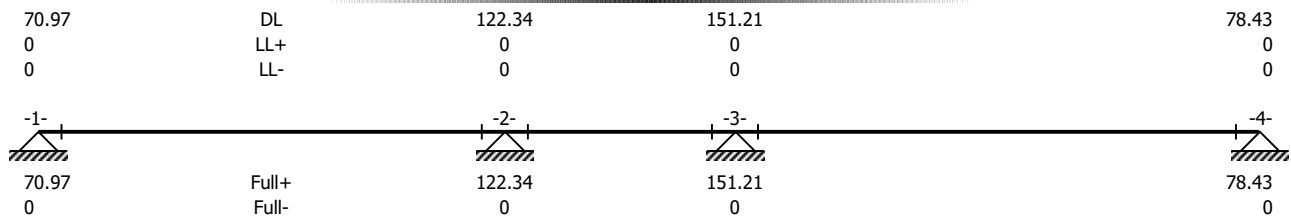
Load Case Is Envelope , Ultimate Strength , U= 1.4 DL + 1.7 LL ,



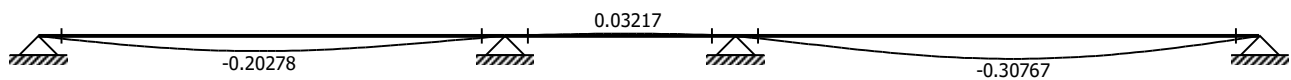
- B.M.D (kN.m) -



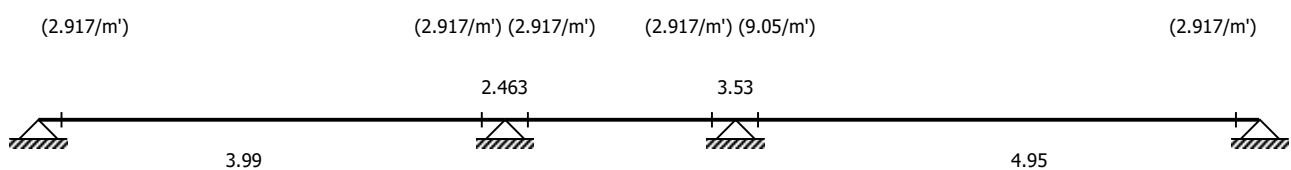
- S.F.D (kN) -



- Reactions (Factored) (kN) -



- Elastic Deformation (Under service loads) (cm) -



- Reinforcement -Bars By User- (cm²) -

Moments

Beam 1 (kN.m)

Span	Mleft+	Mleft-	Mright+	Mright-	Mmax+	X1	Mmax-	X2
1	0	0	0	-39.8	63.12	1.7763	-39.8	4.05
2	0	-39.8	0	-56.18	0	2	-56.18	2
3	0	-56.18	0	0	77.06	2.5594	-56.18	0

Shear Forces

Beam 1 (kN)

Span	Qleft+	Qleft-	Qright+	Qright-	Qmax+	X1	Qmax-	X2
1	70.97	0	0	-90.63	70.97	0	-90.63	4.05
2	31.71	0	0	-48.09	31.71	0	-48.09	2
3	103.12	0	0	-78.43	103.12	0	-78.43	4.55

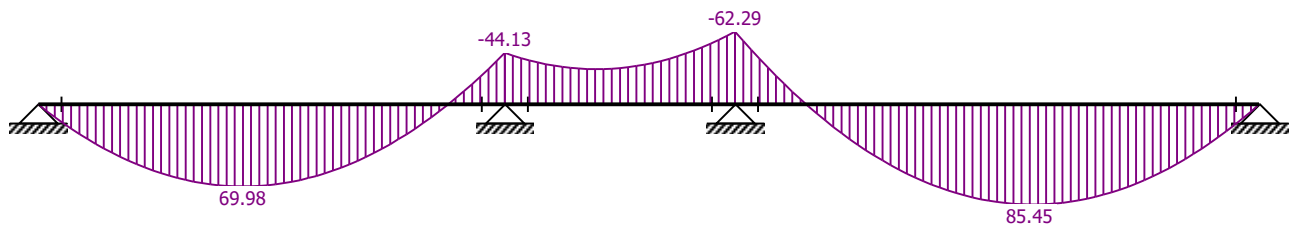
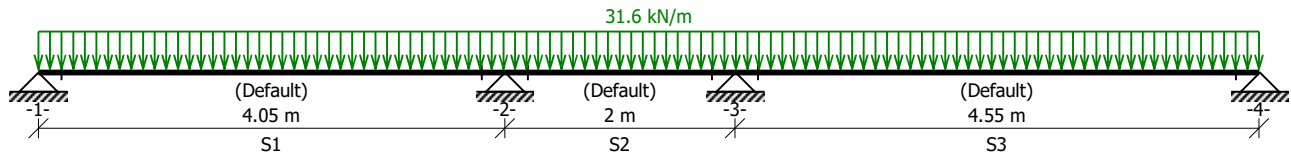
Reactions

Beam 1 (kN) :

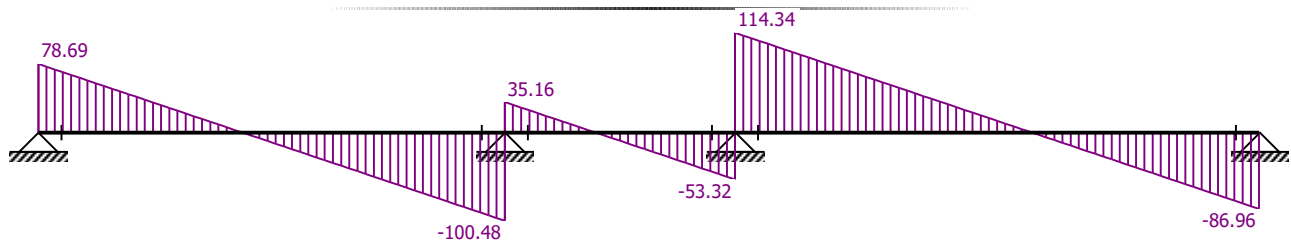
Support	Name	DL	LL+	LL-	Def	Full+	Full-
1		70.97	0	0	0	70.97	0
2		122.34	0	0	0	122.34	0
3		151.21	0	0	0	151.21	0
4		78.43	0	0	0	78.43	0

Beam Name : Beam 1 , Count : 1 , Force's Units : kN , kN/m , kN.m , (Fy=4000, Fey=2400, F'c=180 kgf/cm²)

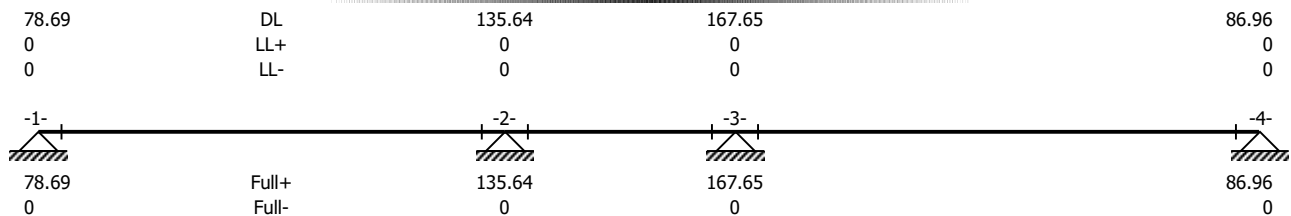
Load Case Is Envelope , Ultimate Strength , U= 1.4 DL + 1.7 LL ,



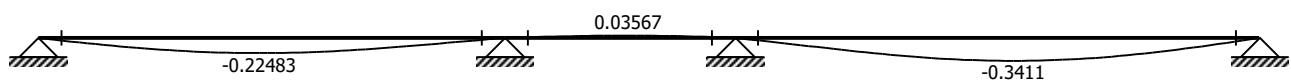
- B.M.D (kN.m) -



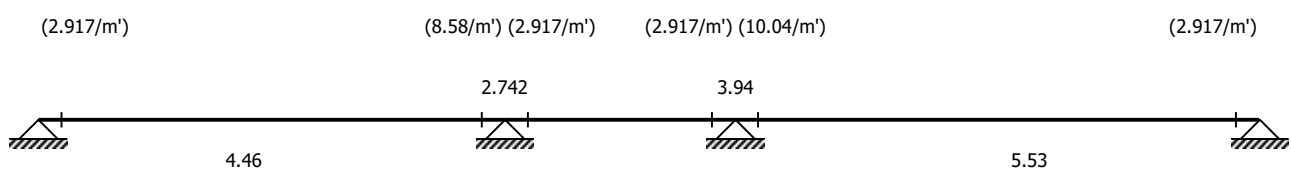
- S.F.D (kN) -



- Reactions (Factored) (kN) -



- Elastic Deformation (Under service loads) (cm) -



- Reinforcement Bars By User- (cm²) -

Moments

Beam 1 (kN.m)

Span	Mleft+	Mleft-	Mright+	Mright-	Mmax+	X1	Mmax-	X2
1	0	0	0	-44.13	69.98	1.7763	-44.13	4.05
2	0	-44.13	0	-62.29	0	2	-62.29	2
3	0	-62.29	0	0	85.45	2.5594	-62.29	0

Shear Forces

Beam 1 (kN)

Span	Qleft+	Qleft-	Qright+	Qright-	Qmax+	X1	Qmax-	X2
1	78.69	0	0	-100.48	78.69	0	-100.48	4.05
2	35.16	0	0	-53.32	35.16	0	-53.32	2
3	114.34	0	0	-86.96	114.34	0	-86.96	4.55

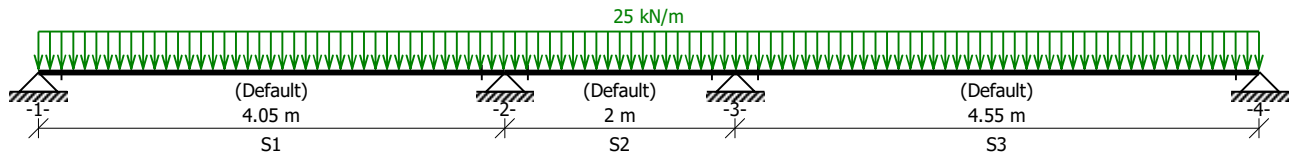
Reactions

Beam 1 (kN) :

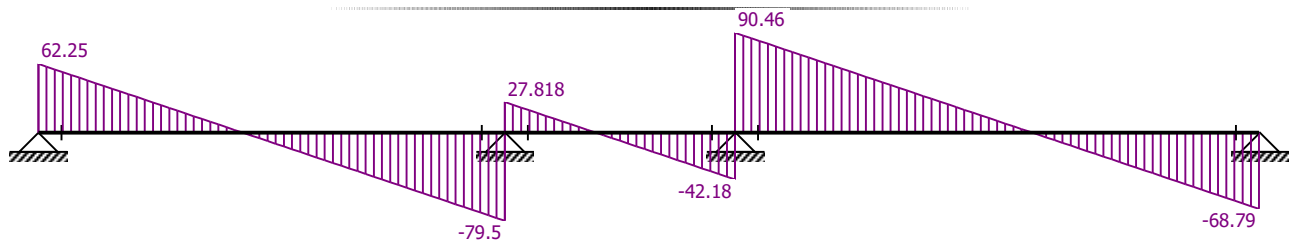
Support	Name	DL	LL+	LL-	Def	Full+	Full-
1		78.69	0	0	0	78.69	0
2		135.64	0	0	0	135.64	0
3		167.65	0	0	0	167.65	0
4		86.96	0	0	0	86.96	0

Beam Name : Beam 1 , Count : 1 , Force's Units : kN , kN/m , kN.m , (Fy=4000, Fey=2400, F'c=180 kgf/cm²)

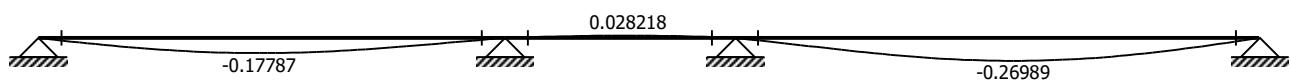
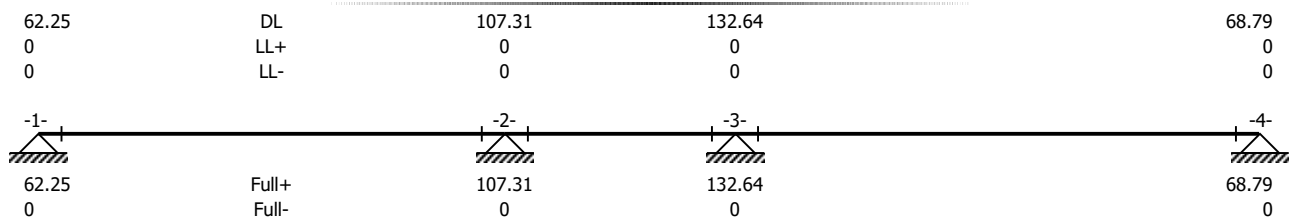
Load Case Is Envelope , , Ultimate Strength , U= 1.4 DL + 1.7 LL ,



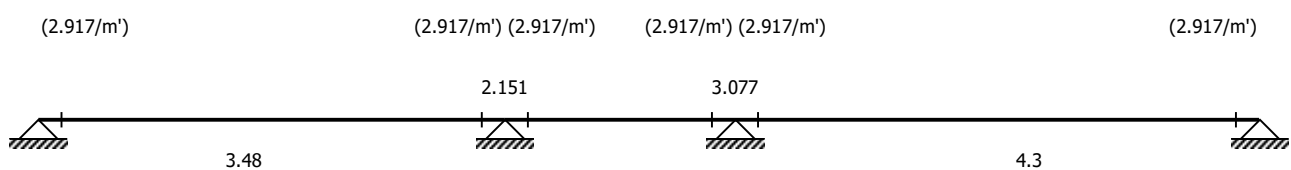
- B.M.D (kN.m) -



- S.F.D (kN) -



- Elastic Deformation (Under service loads) (cm) -



- Reinforcement -Bars By User- (cm²) -

Moments

Beam 1 (kN.m)

Span	Mleft+	Mleft-	Mright+	Mright-	Mmax+	X1	Mmax-	X2
1	0	0	0	-34.91	55.37	1.7763	-34.91	4.05
2	0	-34.91	0	-49.28	0	2	-49.28	2
3	0	-49.28	0	0	67.6	2.5594	-49.28	0

Shear Forces

Beam 1 (kN)

Span	Qleft+	Qleft-	Qright+	Qright-	Qmax+	X1	Qmax-	X2
1	62.25	0	0	-79.5	62.25	0	-79.5	4.05
2	27.818	0	0	-42.18	27.818	0	-42.18	2
3	90.46	0	0	-68.79	90.46	0	-68.79	4.55

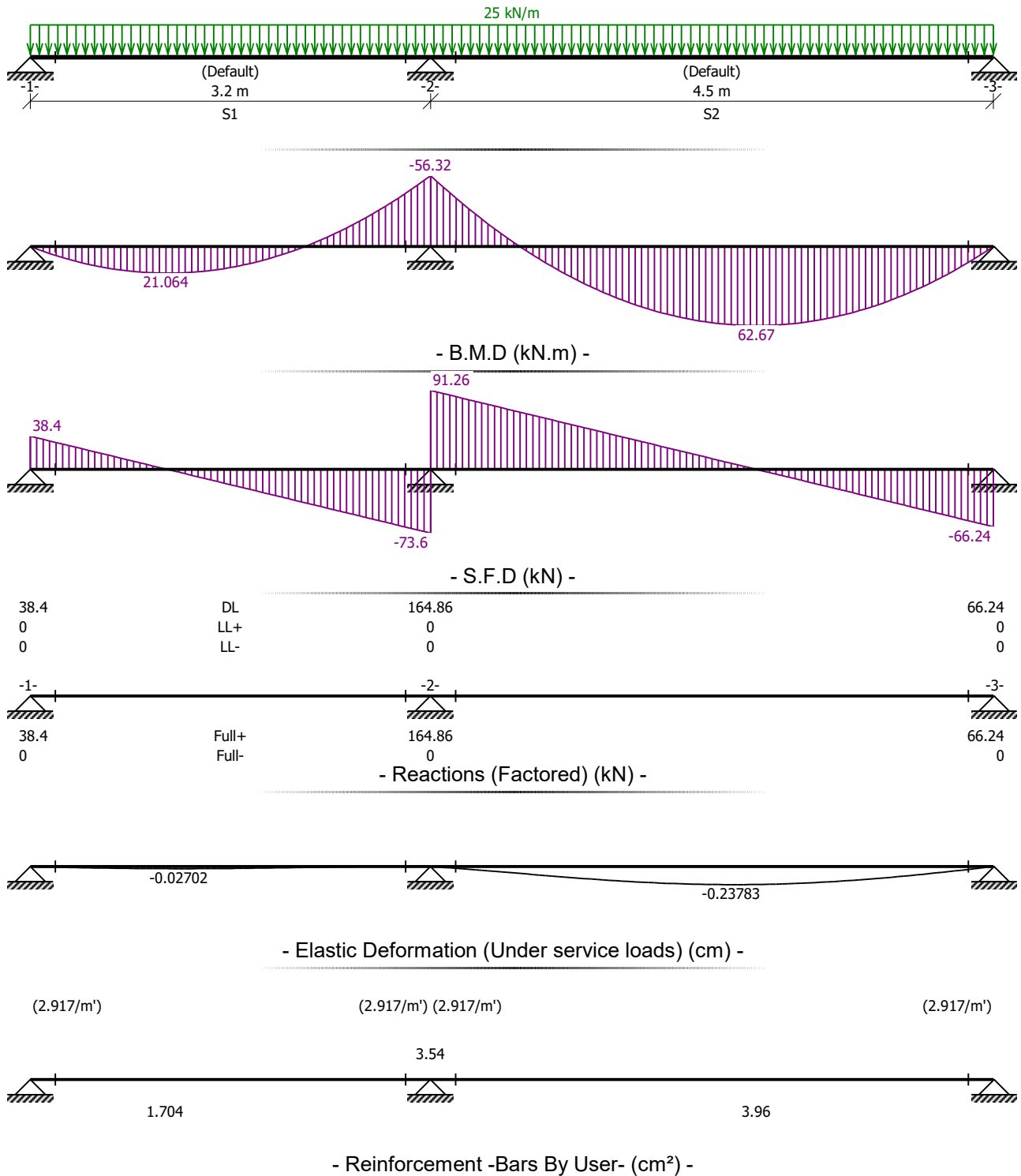
Reactions

Beam 1 (kN) :

Support	Name	DL	LL+	LL-	Def	Full+	Full-
1		62.25	0	0	0	62.25	0
2		107.31	0	0	0	107.31	0
3		132.64	0	0	0	132.64	0
4		68.79	0	0	0	68.79	0

Beam Name : Beam 1 , Count : 1 , Force's Units : kN , kN/m , kN.m , (Fy=4000, Fey=2400, F'c=180 kgf/cm²)

Load Case Is Envelope , Syrian Code 2012 (V.4) , Ultimate Strength , U= 1.4 DL + 1.7 LL ,



Moments

Beam 1 (kN.m)

Span	Mleft+	Mleft-	Mright+	Mright-	Mmax+	X1	Mmax-	X2
1	0	0	0	-56.31	21.064	1.0839	-56.31	3.2
2	0	-56.32	0	0	62.67	2.608	-56.32	0

Shear Forces

Beam 1 (kN)

Span	Qleft+	Qleft-	Qright+	Qright-	Qmax+	X1	Qmax-	X2
1	38.4	0	0	-73.6	38.4	0	-73.6	3.2
2	91.26	0	0	-66.24	91.26	0	-66.24	4.5

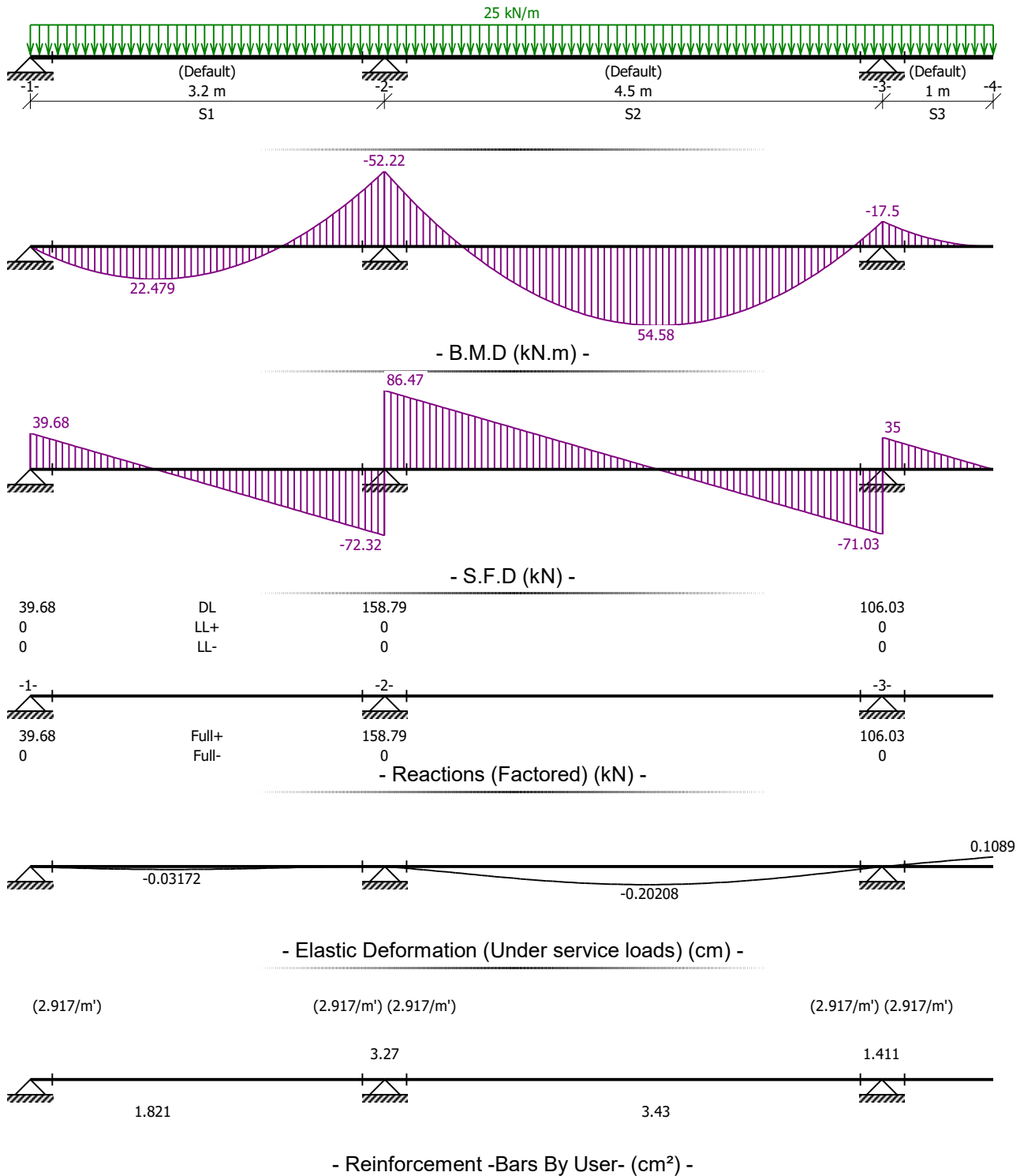
Reactions

Beam 1 (kN) :

Support	Name	DL	LL+	LL-	Def	Full+	Full-
1		38.4	0	0	0	38.4	0
2		164.86	0	0	0	164.86	0
3		66.24	0	0	0	66.24	0

Beam Name : Beam 1 , Count : 1 , Force's Units : kN , kN/m , kN.m , (Fy=4000, Fey=2400, F'c=180 kgf/cm²)

Load Case Is Envelope , Syrian Code 2012 (V.4) , Ultimate Strength , U= 1.4 DL + 1.7 LL ,



Moments

Beam 1 (kN.m)

Span	Mleft+	Mleft-	Mright+	Mright-	Mmax+	X1	Mmax-	X2
1	0	0	0	-52.22	22.479	1.1055	-52.22	3.2
2	0	-52.22	0	-17.5	54.58	2.4545	-52.22	0
3	0	-17.5	0	0	0	1	-17.5	0

Shear Forces

Beam 1 (kN)

Span	Qleft+	Qleft-	Qright+	Qright-	Qmax+	X1	Qmax-	X2
1	39.68	0	0	-72.32	39.68	0	-72.32	3.2
2	86.47	0	0	-71.03	86.47	0	-71.03	4.5
3	35	0	6.25E-05	0	35	0	0	1

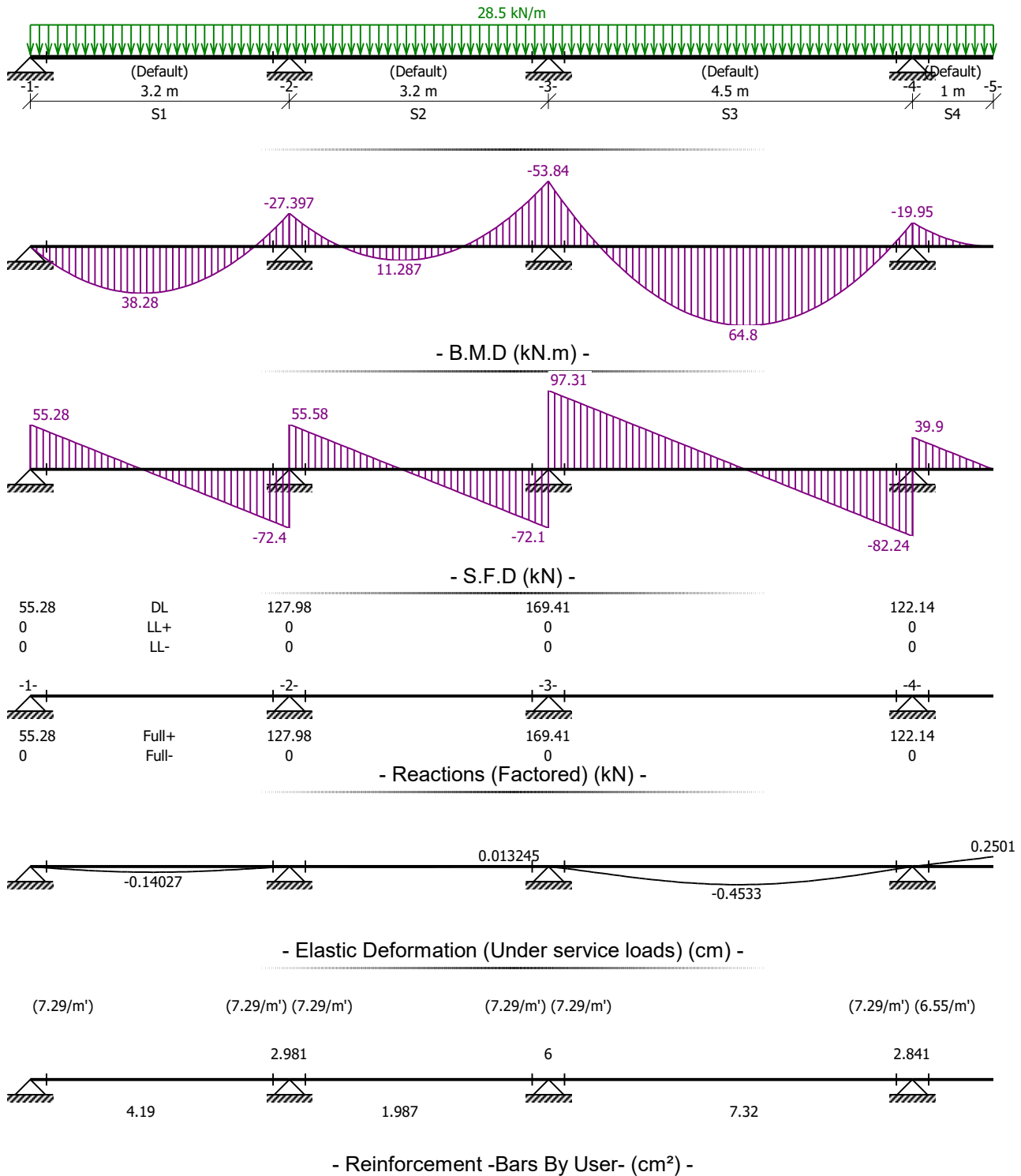
Reactions

Beam 1 (kN) :

Support	Name	DL	LL+	LL-	Def	Full+	Full-
1		39.68	0	0	0	39.68	0
2		158.79	0	0	0	158.79	0
3		106.03	0	0	0	106.03	0
4							

Beam Name : Beam 1 , Count : 1 , Force's Units : kN , kN/m , kN.m , (Fy=4000, Fey=2400, F'c=180 kgf/cm²)

Load Case Is Envelope , Ultimate Strength, U= 1.4 DL + 1.7 LL ,



Moments

Beam 1 (kN.m)

Span	Mleft+	Mleft-	Mright+	Mright-	Mmax+	X1	Mmax-	X2
1	0	0	0	-27.397	38.28	1.36	-27.397	3.2
2	0	-27.397	0	-53.84	11.287	1.36	-53.84	3.2
3	0	-53.84	0	-19.95	64.8	2.4107	-53.84	0
4	0	-19.95	0	0	0	1	-19.95	0

Shear Forces

Beam 1 (kN)

Span	Qleft+	Qleft-	Qright+	Qright-	Qmax+	X1	Qmax-	X2
1	55.28	0	0	-72.4	55.28	0	-72.4	3.2
2	55.58	0	0	-72.1	55.58	0	-72.1	3.2
3	97.31	0	0	-82.24	97.31	0	-82.24	4.5
4	39.9	0	1.1719E-05	0	39.9	0	0	1

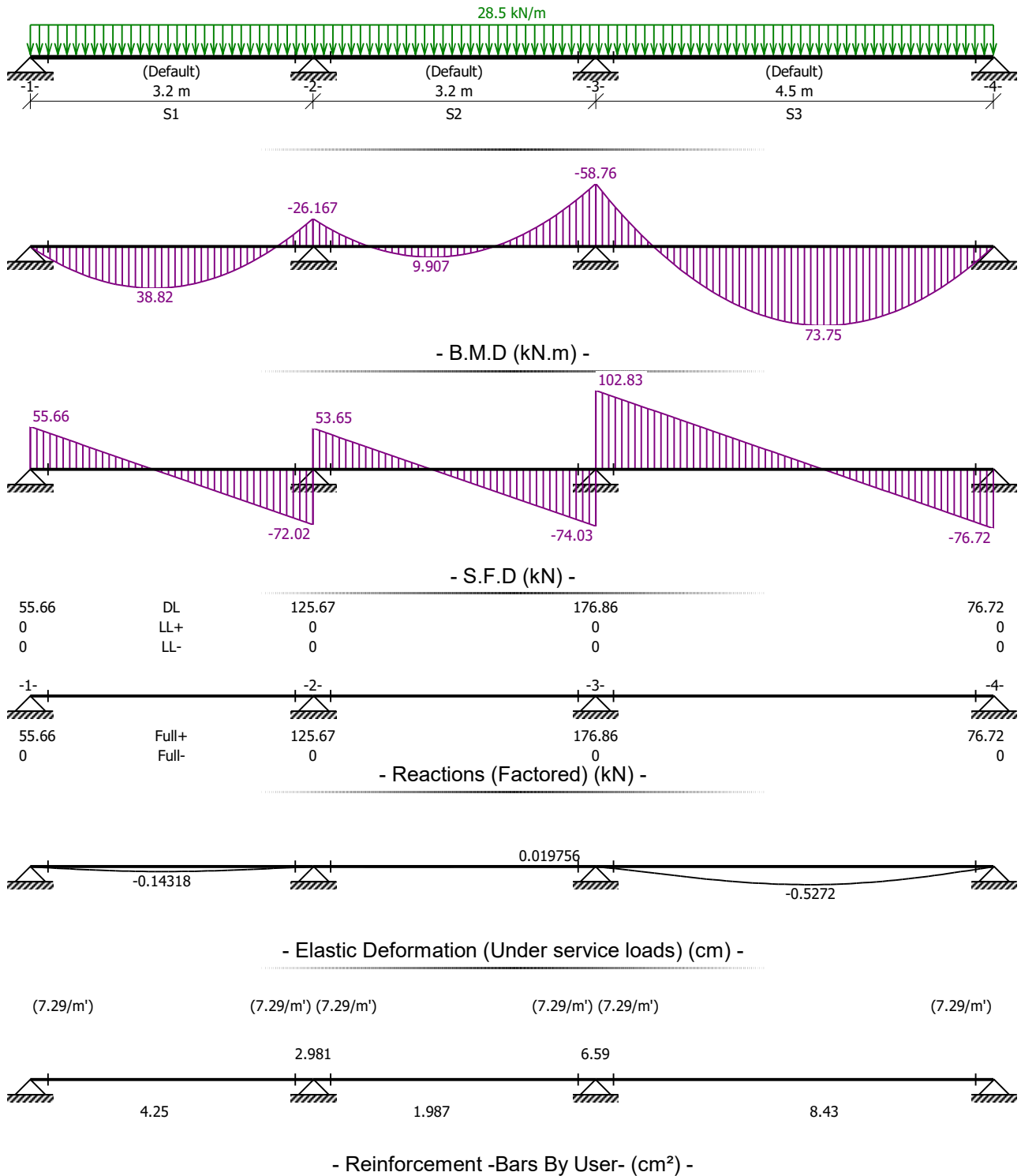
Reactions

Beam 1 (kN) :

Support	Name	DL	LL+	LL-	Def	Full+	Full-
1		55.28	0	0	0	55.28	0
2		127.98	0	0	0	127.98	0
3		169.41	0	0	0	169.41	0
4		122.14	0	0	0	122.14	0
5							

Beam Name : Beam 1 , Count : 1 , Force's Units : kN , kN/m , kN.m , (Fy=4000, Fey=2400, F'c=180 kgf/cm²)

Load Case Is Envelope , Ultimate Strength , U= 1.4 DL + 1.7 LL ,



Moments

Beam 1 (kN.m)

Span	Mleft+	Mleft-	Mright+	Mright-	Mmax+	X1	Mmax-	X2
1	0	0	0	-26.167	38.82	1.414	-26.167	3.2
2	0	-26.167	0	-58.76	9.907	1.3395	-58.76	3.2
3	0	-58.76	0	0	73.75	2.582	-58.76	0

Shear Forces

Beam 1 (kN)

Span	Qleft+	Qleft-	Qright+	Qright-	Qmax+	X1	Qmax-	X2
1	55.66	0	0	-72.02	55.66	0	-72.02	3.2
2	53.65	0	0	-74.03	53.65	0	-74.03	3.2
3	102.83	0	0	-76.72	102.83	0	-76.72	4.5

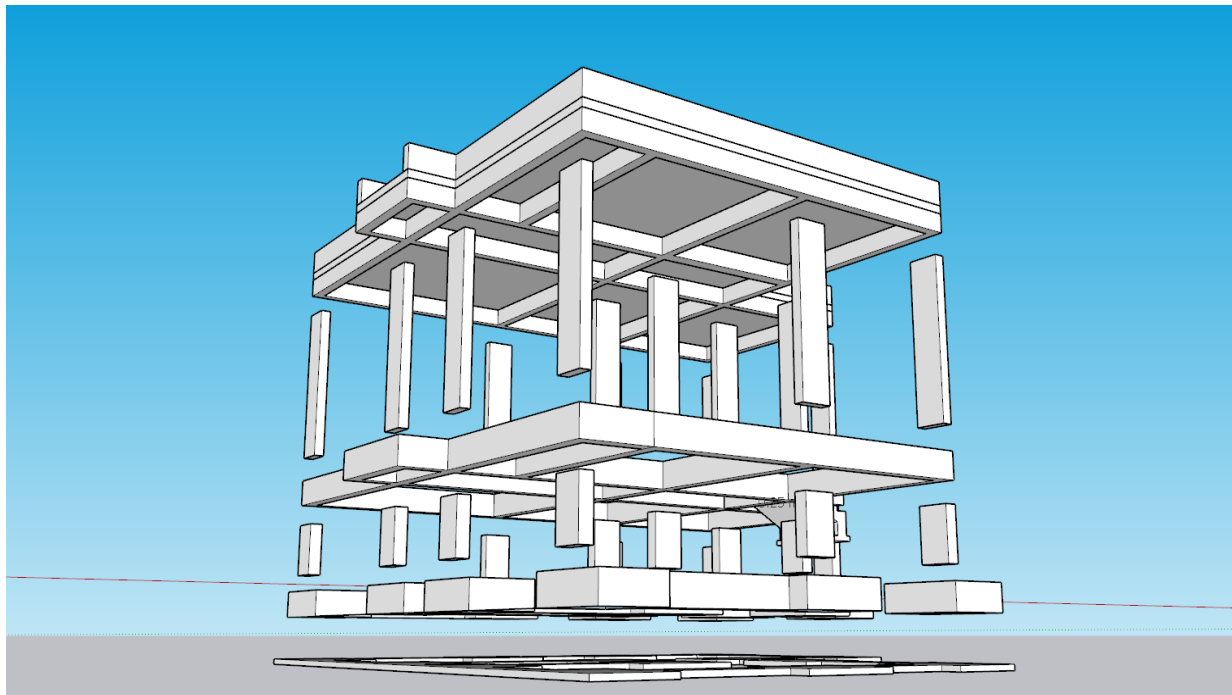
Reactions

Beam 1 (kN) :

Support	Name	DL	LL+	LL-	Def	Full+	Full-
1		55.66	0	0	0	55.66	0
2		125.67	0	0	0	125.67	0
3		176.86	0	0	0	176.86	0
4		76.72	0	0	0	76.72	0

Structural Element Design

2- COLUMNS



REINFORCED CONCRETE COLUMN DESIGN REPORT

Compliance with ACI 318-19 Structural Concrete Building Code

1. Design Input Parameters

Parameter	Symbol / Specification	Value / Unit
Column Width	b	200 mm (20 cm)
Column Depth	h	600 mm (60 cm)
Unbraced Height	lu	3.0 m (3000 mm)
Applied Service Load	P_service	200 kN
Factored Design Axial Load	Pu = 1.6 x P_service	320 kN
Concrete Compressive Strength	f'c	28 MPa (4000 psi)
Steel Yield Strength	fy	420 MPa (Grade 60)
Main Bar Diameter	db	16 mm
Tie Bar Diameter	dt	8 mm
Clear Concrete Cover	cc	40 mm

2. Structural Calculations (ACI 318-19)

2.1 Cross-Sectional Area & Reinforcement Ratio:

- Gross Concrete Area (A_g) = $b \times h = 200 \text{ mm} \times 600 \text{ mm} = 120,000 \text{ mm}^2$
- Minimum Required Steel ($A_{st,min} = 1.0\% A_g$) = $0.01 \times 120,000 = 1,200 \text{ mm}^2$
- Area of single 16 mm bar = $\pi/4 \times 16^2 = 201.06 \text{ mm}^2$
- Number of bars required = $1200 / 201.06 = 5.97 \rightarrow$ Provide 6 $\varnothing$ 16 mm
- Provided Steel Area (A_{st}) = $6 \times 201.06 = 1,206.4 \text{ mm}^2$ ($\rho = 1.005\% \geq 1.0\%$ OK)

2.2 Design Axial Strength Check (ACI 318-19 Sec 22.4.2):

- Formula: $\phi P_n,max = 0.80 \times \phi \times [0.85 \times f'c \times (A_g - A_{st}) + f_y \times A_{st}]$
- Strength reduction factor for tied column (ϕ) = 0.65
- Concrete contribution = $0.85 \times 28 \times (120,000 - 1,206.4) = 2,827,287.5 \text{ N}$
- Steel contribution = $420 \times 1,206.4 = 506,688.0 \text{ N}$

- Nominal Axial Strength ($P_{n,max}$) = $0.80 \times (2,827,287.5 + 506,688.0) = 2,667.2 \text{ kN}$
- Design Axial Capacity ($\phi P_{n,max}$) = $0.65 \times 2,667.2 \text{ kN} = 1,733.7 \text{ kN}$
- Demand-to-Capacity Check: $P_u = 320 \text{ kN} \leq \phi P_{n,max} = 1,733.7 \text{ kN}$ (Ratio = 18.5% -> SAFE)

2.3 Tie Spacing Requirements (ACI 318-19 Sec 25.7.2.1):

- Maximum allowable spacing 's' is the minimum of:
 1. $16 \times \text{main bar diameter} = 16 \times 16 \text{ mm} = 256 \text{ mm}$
 2. $48 \times \text{tie bar diameter} = 48 \times 8 \text{ mm} = 384 \text{ mm}$
 3. Minimum column dimension = 200 mm
- Selected Spacing: $\phi 8 \text{ mm}$ ties @ 150 mm c/c .

3. Summary & Structural Compliance

Component / Requirement	Design Provision	Status / Notes
Dimensions	200 mm x 600 mm x 3000 mm	Adequate
Longitudinal Steel	6 $\phi 16 \text{ mm}$ ($A_{st} = 1206.4 \text{ mm}^2$)	$\rho = 1.005\%$ (Satisfies ACI)
Transverse Ties	$\phi 8 \text{ mm @ } 150 \text{ mm c/c}$	Complies with spacing $\leq 200\text{mm}$
Design Axial Load (P_u)	320.0 kN	Factored load
Design Capacity (ϕP_n)	1,733.7 kN	Safety margin: 5.42x
Overall Status	PASS / STRUCTURALLY SAFE	Fully compliant with ACI 318-19

REINFORCED CONCRETE COLUMN DESIGN REPORT

Designed in Accordance with ACI 318-19 (Building Code Requirements for Structural Concrete)

1. Executive Summary & Input Parameters

This report presents the structural engineering calculation and design verification for a short tied reinforced concrete column with dimensions of 250 mm x 600 mm and an unbraced height of 1.50 meters carrying an unfactored service axial load of 250 kN. All design procedures follow the American Concrete Institute standards (ACI 318-19).

Parameter	Symbol	Specified Value
Column Width	b	250 mm (25 cm)
Column Depth	h	600 mm (60 cm)
Unbraced Height	l_u	1.50 m (1500 mm)
Unfactored Service Axial Load	$P_{service}$	250.0 kN
Factored Design Load (1.6 Service Load)	P_u	400.0 kN
Concrete Compressive Strength	f'_c	28 MPa (~4000 psi)
Steel Yield Strength	f_y	420 MPa (Grade 60)
Main Reinforcement Bar Diameter	d_b	Ø 16 mm

3.1 Slenderness Ratio Evaluation (ACI 318-19 Sec 6.2.5)

- **Radius of Gyration (r):** $r \approx 0.30 \times b = 0.30 \times 250 \text{ mm} = 75 \text{ mm}$
- **Slenderness Ratio ($k \times l_u / r$):** Considering nonsway conditions ($k = 1.0$): $(1.0 \times 1500 \text{ mm}) / 75 \text{ mm} = 20.0$
- **Slenderness Limit Check:** $20.0 \leq 22 \rightarrow$ **Short Column Condition Satisfied (No slenderness or buckling reduction required)**

3.2 Cross-Sectional Area & Reinforcement Ratio

- **Gross Concrete Section Area (A_g):** $A_g = b \times h = 250 \text{ mm} \times 600 \text{ mm} = 150,000 \text{ mm}^2$
- **Minimum Steel Requirement (ACI 318-19 Sec 10.6.1.1):** $A_{st,min} = 1.0\% \times A_g = 0.01 \times 150,000 = 1,500 \text{ mm}^2$
- **Area of Single Ø16 Bar:** $A_b = (\pi / 4) \times 16^2 = 201.06 \text{ mm}^2$
- **Required Number of Bars:** $N = 1500 / 201.06 = 7.46 \text{ bars}$
- **Provided Reinforcement: 8 Ø 16 mm** ($A_{st} = 8 \times 201.06 = 1,608.5 \text{ mm}^2$, $\rho = 1.07\% \geq 1.0\%$)

3.3 Design Axial Strength Check (ACI 318-19 Sec 22.4.2)

- **Nominal Capacity Formula:** $P_{n,max} = 0.80 \times [0.85 \times f'_c \times (A_g - A_{st}) + f_y \times A_{st}]$
- **Strength Reduction Factor (ϕ):** 0.65 (for tied compressive members)
- **Concrete Force Component:** $0.85 \times 28 \text{ MPa} \times (150,000 - 1,608.5) = 3,531,717.7 \text{ N}$ (3,531.7 kN)
- **Steel Force Component:** $420 \text{ MPa} \times 1,608.5 \text{ mm}^2 = 675,570.0 \text{ N}$ (675.6 kN)
- **Total Nominal Capacity ($P_{n,max}$):** $0.80 \times (3,531.7 + 675.6) = 3,325.8 \text{ kN}$
- **Design Axial Capacity ($\phi P_{n,max}$):** $0.65 \times 3,325.8 \text{ kN} = 2,160.8 \text{ kN}$
- **Demand-to-Capacity Check:** P_u (400 kN) $< \phi P_{n,max}$ (2,160.8 kN) $\rightarrow$ **UTILIZATION RATIO = 18.5% (STRUCTURALLY SAFE)**

3.4 Transverse Tie Detailing (ACI 318-19 Sec 25.7.2.1)

The maximum spacing (s) for Ø 8 mm tie bars is governed by the smallest of:

1. $16 \times \text{Longitudinal bar diameter} = 16 \times 16 \text{ mm} = 256 \text{ mm}$
2. $48 \times \text{Tie bar diameter} = 48 \times 8 \text{ mm} = 384 \text{ mm}$
3. Minimum cross-sectional dimension = 250 mm

Design Selection: Use Ø 8 mm ties spaced at 150 mm center-to-center throughout the column height.

4. Design Conclusion & Summary Table

Element / Requirement	Designed Specification	ACI Compliance Status
Column Dimensions	250 mm x 600 mm x 1500 mm	Compliant (Short Column)
Main Steel Reinforcement	8 Ø 16 mm (1,608.5 mm ²)	Passes Minimum Ratio ($\rho = 1.07\%$)
Tie Reinforcement	Ø 8 mm @ 150 mm c/c	Passes Spacing Limits (≤ 250 mm)
Factored Axial Load (P_u)	400.0 kN	Design Load
Design Load Capacity (ϕP_n)	2,160.8 kN	Capacity Exceeds Demand by 5.4x
Final Result	STRUCTURALLY SAFE	FULLY COMPLIANT (ACI 318-19)

Engineering Note: With a height of 1.50 m and dimensions of 25x60 cm, the column qualifies as a short column and is immune to buckling effects. The calculated axial capacity (2,160.8 kN) exceeds the required design load (400 kN) by more than 5 times, offering high structural reliability.

REINFORCED CONCRETE COLUMN DESIGN REPORT

Designed in Accordance with ACI 318-19 (Building Code Requirements for Structural Concrete)

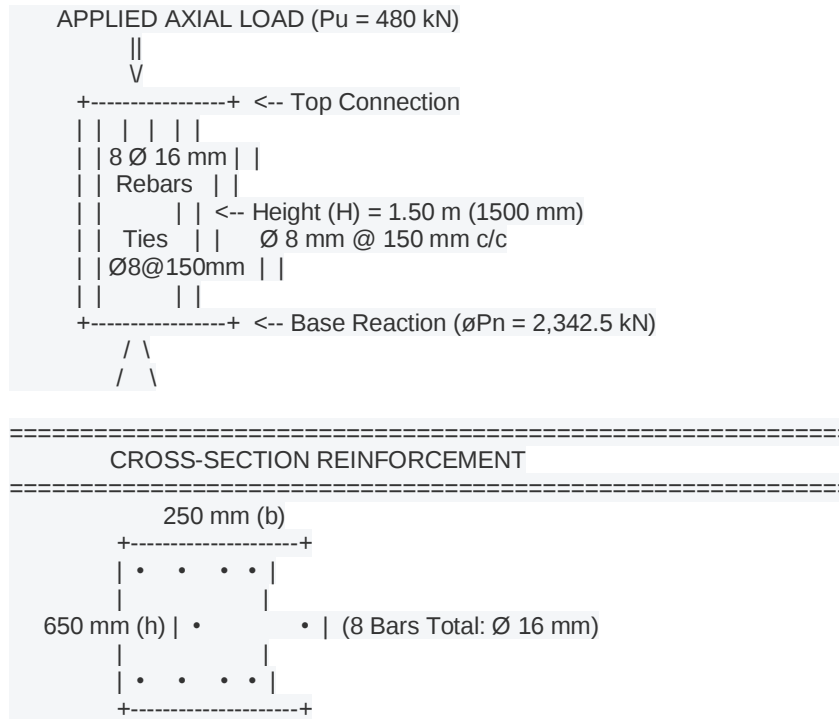
1. Executive Summary & Project Details

This report presents the structural engineering design and strength validation for a short tied reinforced concrete column with an unbraced height of 1.50 meters carrying a service axial load of 300 kN. The analysis and structural detailing adhere strictly to the American Concrete Institute standards (ACI 318-19).

Parameter	Symbol	Specified Value
Column Width	b	250 mm (25 cm)
Column Depth	h	650 mm (65 cm)
Unbraced Height	l_u	1.50 m (1500 mm)
Unfactored Service Axial Load	$P_{service}$	300.0 kN
Factored Design Load (1.6 Service Load)	P_u	480.0 kN
Concrete Compressive Strength	f'_c	28 MPa (~4000 psi)
Steel Yield Strength	f_y	420 MPa (Grade 60)
Main Reinforcement Diameter	d_b	Ø 16 mm
Transverse Tie Diameter	d_t	Ø 8 mm
Clear Concrete Cover	c_c	40 mm (ACI Standard)

2. Axial Force & Action Diagram (Forces Diagram)

The structural force diagram below depicts the applied axial load, unbraced column length, transverse tie spacing, and cross-sectional reinforcement configuration:



3. Structural Calculations & Capacity Verification

3.1 Slenderness Ratio Evaluation (ACI 318-19 Sec 6.2.5)

- **Radius of Gyration (r):** $r \approx 0.30 \times b = 0.30 \times 250 \text{ mm} = 75 \text{ mm}$
- **Slenderness Ratio ($k \times l_u / r$):** Considering nonsway conditions ($k = 1.0$): $(1.0 \times 1500 \text{ mm}) / 75 \text{ mm} = 20.0$
- **Slenderness Limit:** $20.0 \leq 22 \rightarrow$ **Short Column Condition Satisfied** (Slenderness Effects Negligible)

3.2 Cross-Sectional Area & Reinforcement Ratio

- **Gross Concrete Section Area (A_g):** $A_g = b \times h = 250 \text{ mm} \times 650 \text{ mm} = 162,500 \text{ mm}^2$
- **Minimum Steel Requirement (ACI 318-19 Sec 10.6.1.1):** $A_{st,min} = 1.0\% \times A_g = 0.01 \times 162,500 = 1,625 \text{ mm}^2$
- **Area of Single $\phi 16$ Bar:** $A_b = (\pi / 4) \times 16^2 = 201.06 \text{ mm}^2$
- **Required Number of Bars:** $N = 1625 / 201.06 = 8.08 \text{ bars}$

- **Provided Reinforcement: 8 Ø 16 mm** ($A_{st} = 8 \times 201.06 = 1,608.5 \text{ mm}^2$, $\rho = 0.99\% \approx 1.0\%$)

3.3 Design Axial Strength Check (ACI 318-19 Sec 22.4.2)

- **Nominal Strength Formula:** $P_{n,max} = 0.80 \times [0.85 \times f'_c \times (A_g - A_{st}) + f_y \times A_{st}]$
- **Strength Reduction Factor (ϕ):** 0.65 (for tied compressive members)
- **Concrete Force Component:** $0.85 \times 28 \text{ MPa} \times (162,500 - 1,608.5) = 3,829,217.7 \text{ N}$ (3,829.2 kN)
- **Steel Force Component:** $420 \text{ MPa} \times 1,608.5 \text{ mm}^2 = 675,570.0 \text{ N}$ (675.6 kN)
- **Total Nominal Capacity ($P_{n,max}$):** $0.80 \times (3,829.2 + 675.6) = 3,603.8 \text{ kN}$
- **Design Axial Capacity ($\phi P_{n,max}$):** $0.65 \times 3,603.8 \text{ kN} = \mathbf{2,342.5 \text{ kN}}$
- **Demand-to-Capacity Check:** P_u (480 kN) $< \phi P_{n,max}$ (2,342.5 kN) $\rightarrow$ **UTILIZATION RATIO = 20.5% (SAFE)**

3.4 Transverse Tie Detailing (ACI 318-19 Sec 25.7.2.1)

The maximum spacing (s) for Ø 8 mm tie bars is governed by the smallest of:

1. 16 x Longitudinal bar diameter = 16 x 16 mm = 256 mm
2. 48 x Tie bar diameter = 48 x 8 mm = 384 mm
3. Minimum cross-sectional dimension = 250 mm

Design Selection: Use **Ø 8 mm ties spaced at 150 mm center-to-center** throughout the column height.

4. Design Conclusion & Summary Table

Element / Requirement	Designed Specification	ACI Compliance Status
Column Dimensions	250 mm x 650 mm x 1500 mm	Compliant (Short Column)
Main Steel Reinforcement	8 Ø 16 mm (1,608.5 mm ²)	Passes Minimum Ratio ($\rho \approx 1.0\%$)
Tie Reinforcement	Ø 8 mm @ 150 mm c/c	Passes Spacing Limits ($\leq 250 \text{ mm}$)
Factored Axial Load (P_u)	480.0 kN	Demand Load
Design Load Capacity (ϕP_n)	2,342.5 kN	Capacity Exceeds Demand by 4.88x

Element / Requirement	Designed Specification	ACI Compliance Status
Final Result	STRUCTURALLY SAFE	FULLY COMPLIANT (ACI 318-19)

Engineering Note: With a height of 1.50 m, the column is structurally classified as a short column, completely immune to slenderness or buckling effects. The 25x65 cm section capacity (2,342.5 kN) significantly exceeds the design load (480 kN), providing exceptional safety margins and vertical load stability.

REINFORCED CONCRETE COLUMN DESIGN REPORT

Compliance with ACI 318-19 Structural Concrete Building Code

1. Design Input Parameters

Parameter	Symbol / Spec	Value / Unit
Column Width	b	200 mm (20 cm)
Column Depth	h	600 mm (60 cm)
Unbraced Length	l _u	3.0 m (3000 mm)
Applied Axial Service Load	P _{service}	250 kN
Factored Design Axial Load	P _u = 1.6 x P _{service}	400 kN
Concrete Compressive Strength	f' _c	28 MPa
Steel Yield Strength	f _y	420 MPa
Main Reinforcement Diameter	d _b	16 mm
Tie Reinforcement Diameter	d _t	8 mm
Clear Concrete Cover	cc	40 mm

2. Structural Calculation Steps (ACI 318-19)

2.1 Cross-Sectional Area & Minimum Steel Requirement

- Gross Cross-Sectional Area (A_g):
 $A_g = b \times h = 200 \text{ mm} \times 600 \text{ mm} = 120,000 \text{ mm}^2$
- Minimum Required Steel Area (A_{st,min} = 1.0% A_g per ACI 318-19 Section 10.6.1.1):
 $A_{st,min} = 0.01 \times 120,000 \text{ mm}^2 = 1,200 \text{ mm}^2$
- Selected Main Reinforcement:
Area of single 16 mm bar (A_b) = $\pi/4 \times (16)^2 = 201.06 \text{ mm}^2$

Number of bars required = $1,200 / 201.06 = 5.97 \rightarrow$ Provide 6 Bars (6 $\emptyset$ 16 mm)
Provided Steel Area (A_{st}) = $6 \times 201.06 \text{ mm}^2 = 1,206.4 \text{ mm}^2$ ($\rho = 1.005\% \geq 1.0\%$ OK)

2.2 Nominal & Design Axial Strength (ACI 318-19 Section 22.4.2)

For tied columns, the maximum design axial strength $\phi P_{n,max}$ is given by:

$$\phi P_{n,max} = 0.80 \times \phi \times [0.85 \times f'_c \times (A_g - A_{st}) + f_y \times A_{st}]$$

Where strength reduction factor $\phi = 0.65$ for compression-controlled tied members.

- Substitute values:

$$0.85 \times f'_c \times (A_g - A_{st}) = 0.85 \times 28 \times (120,000 - 1,206.4) = 2,827,287.5 \text{ N}$$

$$f_y \times A_{st} = 420 \times 1,206.4 = 506,688.0 \text{ N}$$

$$P_{n,max} = 0.80 \times [2,827,287.5 + 506,688.0] = 2,667,180.4 \text{ N} = 2,667.2 \text{ kN}$$

$$\phi P_{n,max} = 0.65 \times 2,667.2 \text{ kN} = 1,733.7 \text{ kN}$$

- Demand-to-Capacity Check:

$$P_u = 400 \text{ kN} \leq \phi P_{n,max} = 1,733.7 \text{ kN} \quad [\text{CAPACITY UTILIZATION} = 23.1\% \rightarrow \text{SAFE}]$$

2.3 Transverse Reinforcement / Tie Spacing (ACI 318-19 Section 25.7.2.1)

Maximum spacing of tie reinforcement 's' shall not exceed the smallest of:

- $16 \times$ longitudinal bar diameter = $16 \times 16 \text{ mm} = 256 \text{ mm}$
- $48 \times$ tie bar diameter = $48 \times 8 \text{ mm} = 384 \text{ mm}$
- Smallest cross-sectional dimension = 200 mm

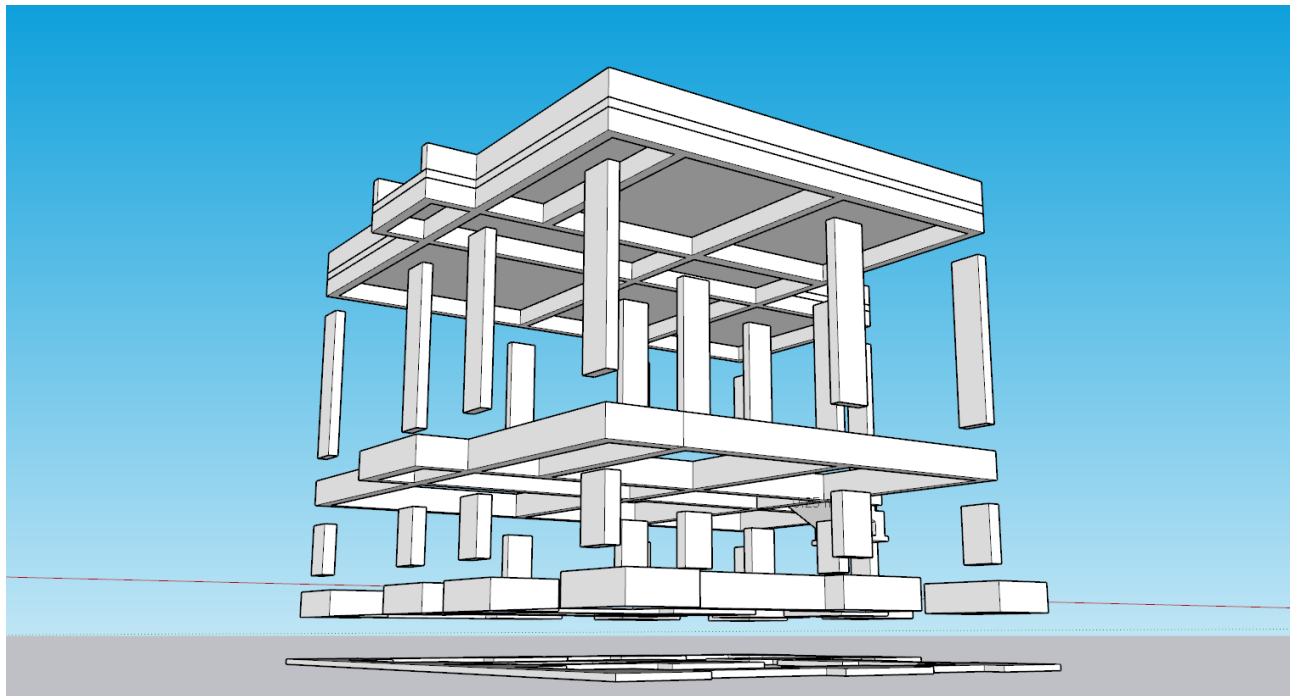
- Selected Tie Spacing: Use $\emptyset$ 8 mm ties @ 150 mm c/c (Conservative & Practical).

3. Design Summary & Conclusion

Component / Requirement	Designed Provision	Status / Notes
Column Dimensions	200 mm x 600 mm x 3000 mm	Adequate
Main Reinforcement	6 $\emptyset$ 16 mm ($A_{st} = 1206.4 \text{ mm}^2$)	$\rho = 1.005\%$ (Satisfies ACI)
Tie Reinforcement	$\emptyset$ 8 mm @ 150 mm c/c	Satisfies spacing limit ($\leq 200\text{mm}$)
Design Axial Load (P_u)	400.0 kN	Factored load
Design Axial Capacity (ϕP_n)	1733.7 kN	Safety Margin: 4.33x
Overall Design Status	PASS / STRUCTURALLY SAFE	Fully compliant with ACI 318-19

Structural Element Design

3-UNDERGROUND BEAM



REINFORCED CONCRETE COLUMN DESIGN REPORT

Compliance with ACI 318-19 Structural Concrete Building Code

1. Design Input Parameters

Parameter	Symbol / Specification	Value / Unit
Column Width	b	200 mm (20 cm)
Column Depth	h	600 mm (60 cm)
Unbraced Height	lu	3.0 m (3000 mm)
Applied Service Load	P_service	200 kN
Factored Design Axial Load	Pu = 1.6 x P_service	320 kN
Concrete Compressive Strength	f'c	28 MPa (4000 psi)
Steel Yield Strength	fy	420 MPa (Grade 60)
Main Bar Diameter	db	16 mm
Tie Bar Diameter	dt	8 mm
Clear Concrete Cover	cc	40 mm

2. Structural Calculations (ACI 318-19)

2.1 Cross-Sectional Area & Reinforcement Ratio:

- Gross Concrete Area (A_g) = $b \times h = 200 \text{ mm} \times 600 \text{ mm} = 120,000 \text{ mm}^2$
- Minimum Required Steel ($A_{st,min} = 1.0\% A_g$) = $0.01 \times 120,000 = 1,200 \text{ mm}^2$
- Area of single 16 mm bar = $\pi/4 \times 16^2 = 201.06 \text{ mm}^2$
- Number of bars required = $1200 / 201.06 = 5.97 \rightarrow$ Provide 6 $\varnothing$ 16 mm
- Provided Steel Area (A_{st}) = $6 \times 201.06 = 1,206.4 \text{ mm}^2$ ($\rho = 1.005\% \geq 1.0\%$ OK)

2.2 Design Axial Strength Check (ACI 318-19 Sec 22.4.2):

- Formula: $\phi P_n,max = 0.80 \times \phi \times [0.85 \times f'c \times (A_g - A_{st}) + f_y \times A_{st}]$
- Strength reduction factor for tied column (ϕ) = 0.65
- Concrete contribution = $0.85 \times 28 \times (120,000 - 1,206.4) = 2,827,287.5 \text{ N}$
- Steel contribution = $420 \times 1,206.4 = 506,688.0 \text{ N}$

- Nominal Axial Strength ($P_{n,max}$) = $0.80 \times (2,827,287.5 + 506,688.0) = 2,667.2 \text{ kN}$
- Design Axial Capacity ($\phi P_{n,max}$) = $0.65 \times 2,667.2 \text{ kN} = 1,733.7 \text{ kN}$
- Demand-to-Capacity Check: $P_u = 320 \text{ kN} \leq \phi P_{n,max} = 1,733.7 \text{ kN}$ (Ratio = 18.5% -> SAFE)

2.3 Tie Spacing Requirements (ACI 318-19 Sec 25.7.2.1):

- Maximum allowable spacing 's' is the minimum of:
 1. $16 \times \text{main bar diameter} = 16 \times 16 \text{ mm} = 256 \text{ mm}$
 2. $48 \times \text{tie bar diameter} = 48 \times 8 \text{ mm} = 384 \text{ mm}$
 3. Minimum column dimension = 200 mm
- Selected Spacing: $\phi 8 \text{ mm}$ ties @ 150 mm c/c.

3. Summary & Structural Compliance

Component / Requirement	Design Provision	Status / Notes
Dimensions	200 mm x 600 mm x 3000 mm	Adequate
Longitudinal Steel	6 $\phi 16 \text{ mm}$ ($A_{st} = 1206.4 \text{ mm}^2$)	$\rho = 1.005\%$ (Satisfies ACI)
Transverse Ties	$\phi 8 \text{ mm}$ @ 150 mm c/c	Complies with spacing $\leq 200\text{mm}$
Design Axial Load (P_u)	320.0 kN	Factored load
Design Capacity (ϕP_n)	1,733.7 kN	Safety margin: 5.42x
Overall Status	PASS / STRUCTURALLY SAFE	Fully compliant with ACI 318-19

REINFORCED CONCRETE COLUMN DESIGN REPORT

Designed in Accordance with ACI 318-19 (Building Code Requirements for Structural Concrete)

1. Executive Summary & Input Parameters

This report presents the structural engineering calculation and design verification for a short tied reinforced concrete column with dimensions of 250 mm x 600 mm and an unbraced height of 1.50 meters carrying an unfactored service axial load of 250 kN. All design procedures follow the American Concrete Institute standards (ACI 318-19).

Parameter	Symbol	Specified Value
Column Width	b	250 mm (25 cm)
Column Depth	h	600 mm (60 cm)
Unbraced Height	l_u	1.50 m (1500 mm)
Unfactored Service Axial Load	$P_{service}$	250.0 kN
Factored Design Load (1.6 Service Load)	P_u	400.0 kN
Concrete Compressive Strength	f'_c	28 MPa (~4000 psi)
Steel Yield Strength	f_y	420 MPa (Grade 60)
Main Reinforcement Bar Diameter	d_b	Ø 16 mm

3.1 Slenderness Ratio Evaluation (ACI 318-19 Sec 6.2.5)

- **Radius of Gyration (r):** $r \approx 0.30 \times b = 0.30 \times 250 \text{ mm} = 75 \text{ mm}$
- **Slenderness Ratio ($k \times l_u / r$):** Considering nonsway conditions ($k = 1.0$): $(1.0 \times 1500 \text{ mm}) / 75 \text{ mm} = 20.0$
- **Slenderness Limit Check:** $20.0 \leq 22 \rightarrow$ **Short Column Condition Satisfied (No slenderness or buckling reduction required)**

3.2 Cross-Sectional Area & Reinforcement Ratio

- **Gross Concrete Section Area (A_g):** $A_g = b \times h = 250 \text{ mm} \times 600 \text{ mm} = 150,000 \text{ mm}^2$
- **Minimum Steel Requirement (ACI 318-19 Sec 10.6.1.1):** $A_{st,min} = 1.0\% \times A_g = 0.01 \times 150,000 = 1,500 \text{ mm}^2$
- **Area of Single Ø16 Bar:** $A_b = (\pi / 4) \times 16^2 = 201.06 \text{ mm}^2$
- **Required Number of Bars:** $N = 1500 / 201.06 = 7.46 \text{ bars}$
- **Provided Reinforcement: 8 Ø 16 mm** ($A_{st} = 8 \times 201.06 = 1,608.5 \text{ mm}^2$, $\rho = 1.07\% \geq 1.0\%$)

3.3 Design Axial Strength Check (ACI 318-19 Sec 22.4.2)

- **Nominal Capacity Formula:** $P_{n,max} = 0.80 \times [0.85 \times f'_c \times (A_g - A_{st}) + f_y \times A_{st}]$
- **Strength Reduction Factor (ϕ):** 0.65 (for tied compressive members)
- **Concrete Force Component:** $0.85 \times 28 \text{ MPa} \times (150,000 - 1,608.5) = 3,531,717.7 \text{ N}$ (3,531.7 kN)
- **Steel Force Component:** $420 \text{ MPa} \times 1,608.5 \text{ mm}^2 = 675,570.0 \text{ N}$ (675.6 kN)
- **Total Nominal Capacity ($P_{n,max}$):** $0.80 \times (3,531.7 + 675.6) = 3,325.8 \text{ kN}$
- **Design Axial Capacity ($\phi P_{n,max}$):** $0.65 \times 3,325.8 \text{ kN} = \mathbf{2,160.8 \text{ kN}}$
- **Demand-to-Capacity Check:** P_u (400 kN) $< \phi P_{n,max}$ (2,160.8 kN) $\rightarrow$ **UTILIZATION RATIO = 18.5% (STRUCTURALLY SAFE)**

3.4 Transverse Tie Detailing (ACI 318-19 Sec 25.7.2.1)

The maximum spacing (s) for Ø 8 mm tie bars is governed by the smallest of:

1. $16 \times \text{Longitudinal bar diameter} = 16 \times 16 \text{ mm} = 256 \text{ mm}$
2. $48 \times \text{Tie bar diameter} = 48 \times 8 \text{ mm} = 384 \text{ mm}$
3. Minimum cross-sectional dimension = 250 mm

Design Selection: Use Ø 8 mm ties spaced at 150 mm center-to-center throughout the column height.

4. Design Conclusion & Summary Table

Element / Requirement	Designed Specification	ACI Compliance Status
Column Dimensions	250 mm x 600 mm x 1500 mm	Compliant (Short Column)
Main Steel Reinforcement	8 Ø 16 mm (1,608.5 mm ²)	Passes Minimum Ratio ($\rho = 1.07\%$)
Tie Reinforcement	Ø 8 mm @ 150 mm c/c	Passes Spacing Limits (≤ 250 mm)
Factored Axial Load (P_u)	400.0 kN	Design Load
Design Load Capacity (ϕP_n)	2,160.8 kN	Capacity Exceeds Demand by 5.4x
Final Result	STRUCTURALLY SAFE	FULLY COMPLIANT (ACI 318-19)

Engineering Note: With a height of 1.50 m and dimensions of 25x60 cm, the column qualifies as a short column and is immune to buckling effects. The calculated axial capacity (2,160.8 kN) exceeds the required design load (400 kN) by more than 5 times, offering high structural reliability.

REINFORCED CONCRETE COLUMN DESIGN REPORT

Designed in Accordance with ACI 318-19 (Building Code Requirements for Structural Concrete)

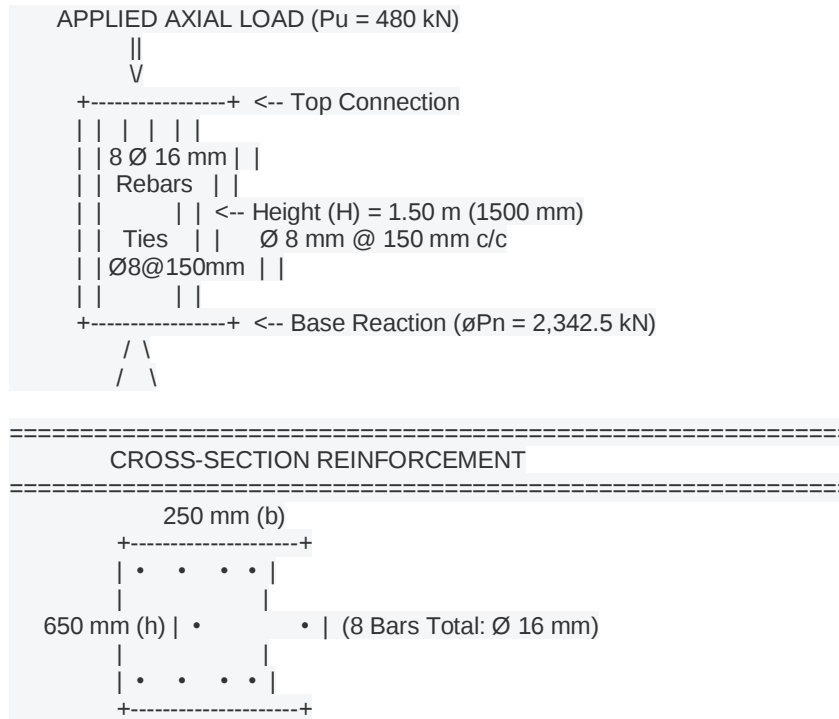
1. Executive Summary & Project Details

This report presents the structural engineering design and strength validation for a short tied reinforced concrete column with an unbraced height of 1.50 meters carrying a service axial load of 300 kN. The analysis and structural detailing adhere strictly to the American Concrete Institute standards (ACI 318-19).

Parameter	Symbol	Specified Value
Column Width	b	250 mm (25 cm)
Column Depth	h	650 mm (65 cm)
Unbraced Height	l_u	1.50 m (1500 mm)
Unfactored Service Axial Load	$P_{service}$	300.0 kN
Factored Design Load (1.6 Service Load)	P_u	480.0 kN
Concrete Compressive Strength	f'_c	28 MPa (~4000 psi)
Steel Yield Strength	f_y	420 MPa (Grade 60)
Main Reinforcement Diameter	d_b	Ø 16 mm
Transverse Tie Diameter	d_t	Ø 8 mm
Clear Concrete Cover	c_c	40 mm (ACI Standard)

2. Axial Force & Action Diagram (Forces Diagram)

The structural force diagram below depicts the applied axial load, unbraced column length, transverse tie spacing, and cross-sectional reinforcement configuration:



3. Structural Calculations & Capacity Verification

3.1 Slenderness Ratio Evaluation (ACI 318-19 Sec 6.2.5)

- **Radius of Gyration (r):** $r \approx 0.30 \times b = 0.30 \times 250 \text{ mm} = 75 \text{ mm}$
- **Slenderness Ratio ($k \times l_u / r$):** Considering nonsway conditions ($k = 1.0$): $(1.0 \times 1500 \text{ mm}) / 75 \text{ mm} = 20.0$
- **Slenderness Limit:** $20.0 \leq 22 \rightarrow$ **Short Column Condition Satisfied** (Slenderness Effects Negligible)

3.2 Cross-Sectional Area & Reinforcement Ratio

- **Gross Concrete Section Area (A_g):** $A_g = b \times h = 250 \text{ mm} \times 650 \text{ mm} = 162,500 \text{ mm}^2$
- **Minimum Steel Requirement (ACI 318-19 Sec 10.6.1.1):** $A_{s,min} = 1.0\% \times A_g = 0.01 \times 162,500 = 1,625 \text{ mm}^2$
- **Area of Single $\text{Ø}16$ Bar:** $A_b = (\pi / 4) \times 16^2 = 201.06 \text{ mm}^2$
- **Required Number of Bars:** $N = 1625 / 201.06 = 8.08 \text{ bars}$

- **Provided Reinforcement: 8 Ø 16 mm** ($A_{st} = 8 \times 201.06 = 1,608.5 \text{ mm}^2$, $\rho = 0.99\% \approx 1.0\%$)

3.3 Design Axial Strength Check (ACI 318-19 Sec 22.4.2)

- **Nominal Strength Formula:** $P_{n,max} = 0.80 \times [0.85 \times f'_c \times (A_g - A_{st}) + f_y \times A_{st}]$
- **Strength Reduction Factor (ϕ):** 0.65 (for tied compressive members)
- **Concrete Force Component:** $0.85 \times 28 \text{ MPa} \times (162,500 - 1,608.5) = 3,829,217.7 \text{ N}$ (3,829.2 kN)
- **Steel Force Component:** $420 \text{ MPa} \times 1,608.5 \text{ mm}^2 = 675,570.0 \text{ N}$ (675.6 kN)
- **Total Nominal Capacity ($P_{n,max}$):** $0.80 \times (3,829.2 + 675.6) = 3,603.8 \text{ kN}$
- **Design Axial Capacity ($\phi P_{n,max}$):** $0.65 \times 3,603.8 \text{ kN} = \mathbf{2,342.5 \text{ kN}}$
- **Demand-to-Capacity Check:** P_u (480 kN) $< \phi P_{n,max}$ (2,342.5 kN) $\rightarrow$ **UTILIZATION RATIO = 20.5% (SAFE)**

3.4 Transverse Tie Detailing (ACI 318-19 Sec 25.7.2.1)

The maximum spacing (s) for Ø 8 mm tie bars is governed by the smallest of:

1. 16 x Longitudinal bar diameter = 16 x 16 mm = 256 mm
2. 48 x Tie bar diameter = 48 x 8 mm = 384 mm
3. Minimum cross-sectional dimension = 250 mm

Design Selection: Use **Ø 8 mm ties spaced at 150 mm center-to-center** throughout the column height.

4. Design Conclusion & Summary Table

Element / Requirement	Designed Specification	ACI Compliance Status
Column Dimensions	250 mm x 650 mm x 1500 mm	Compliant (Short Column)
Main Steel Reinforcement	8 Ø 16 mm (1,608.5 mm ²)	Passes Minimum Ratio ($\rho \approx 1.0\%$)
Tie Reinforcement	Ø 8 mm @ 150 mm c/c	Passes Spacing Limits ($\leq 250 \text{ mm}$)
Factored Axial Load (P_u)	480.0 kN	Demand Load
Design Load Capacity (ϕP_n)	2,342.5 kN	Capacity Exceeds Demand by 4.88x

Element / Requirement	Designed Specification	ACI Compliance Status
Final Result	STRUCTURALLY SAFE	FULLY COMPLIANT (ACI 318-19)

Engineering Note: With a height of 1.50 m, the column is structurally classified as a short column, completely immune to slenderness or buckling effects. The 25x65 cm section capacity (2,342.5 kN) significantly exceeds the design load (480 kN), providing exceptional safety margins and vertical load stability.

REINFORCED CONCRETE COLUMN DESIGN REPORT

Compliance with ACI 318-19 Structural Concrete Building Code

1. Design Input Parameters

Parameter	Symbol / Spec	Value / Unit
Column Width	b	200 mm (20 cm)
Column Depth	h	600 mm (60 cm)
Unbraced Length	l _u	3.0 m (3000 mm)
Applied Axial Service Load	P _{service}	250 kN
Factored Design Axial Load	P _u = 1.6 x P _{service}	400 kN
Concrete Compressive Strength	f' _c	28 MPa
Steel Yield Strength	f _y	420 MPa
Main Reinforcement Diameter	d _b	16 mm
Tie Reinforcement Diameter	d _t	8 mm
Clear Concrete Cover	cc	40 mm

2. Structural Calculation Steps (ACI 318-19)

2.1 Cross-Sectional Area & Minimum Steel Requirement

- Gross Cross-Sectional Area (A_g):
 $A_g = b \times h = 200 \text{ mm} \times 600 \text{ mm} = 120,000 \text{ mm}^2$
- Minimum Required Steel Area (A_{st,min} = 1.0% A_g per ACI 318-19 Section 10.6.1.1):
 $A_{st,min} = 0.01 \times 120,000 \text{ mm}^2 = 1,200 \text{ mm}^2$
- Selected Main Reinforcement:
Area of single 16 mm bar (A_b) = $\pi/4 \times (16)^2 = 201.06 \text{ mm}^2$

Number of bars required = $1,200 / 201.06 = 5.97 \rightarrow$ Provide 6 Bars (6 $\emptyset$ 16 mm)
Provided Steel Area (A_{st}) = $6 \times 201.06 \text{ mm}^2 = 1,206.4 \text{ mm}^2$ ($\rho = 1.005\% \geq 1.0\%$ OK)

2.2 Nominal & Design Axial Strength (ACI 318-19 Section 22.4.2)

For tied columns, the maximum design axial strength $\phi P_{n,max}$ is given by:

$$\phi P_{n,max} = 0.80 \times \phi \times [0.85 \times f'_c \times (A_g - A_{st}) + f_y \times A_{st}]$$

Where strength reduction factor $\phi = 0.65$ for compression-controlled tied members.

- Substitute values:

$$0.85 \times f'_c \times (A_g - A_{st}) = 0.85 \times 28 \times (120,000 - 1,206.4) = 2,827,287.5 \text{ N}$$

$$f_y \times A_{st} = 420 \times 1,206.4 = 506,688.0 \text{ N}$$

$$P_{n,max} = 0.80 \times [2,827,287.5 + 506,688.0] = 2,667,180.4 \text{ N} = 2,667.2 \text{ kN}$$

$$\phi P_{n,max} = 0.65 \times 2,667.2 \text{ kN} = 1,733.7 \text{ kN}$$

- Demand-to-Capacity Check:

$$P_u = 400 \text{ kN} \leq \phi P_{n,max} = 1,733.7 \text{ kN} \quad [\text{CAPACITY UTILIZATION} = 23.1\% \rightarrow \text{SAFE}]$$

2.3 Transverse Reinforcement / Tie Spacing (ACI 318-19 Section 25.7.2.1)

Maximum spacing of tie reinforcement 's' shall not exceed the smallest of:

- $16 \times$ longitudinal bar diameter = $16 \times 16 \text{ mm} = 256 \text{ mm}$
- $48 \times$ tie bar diameter = $48 \times 8 \text{ mm} = 384 \text{ mm}$
- Smallest cross-sectional dimension = 200 mm

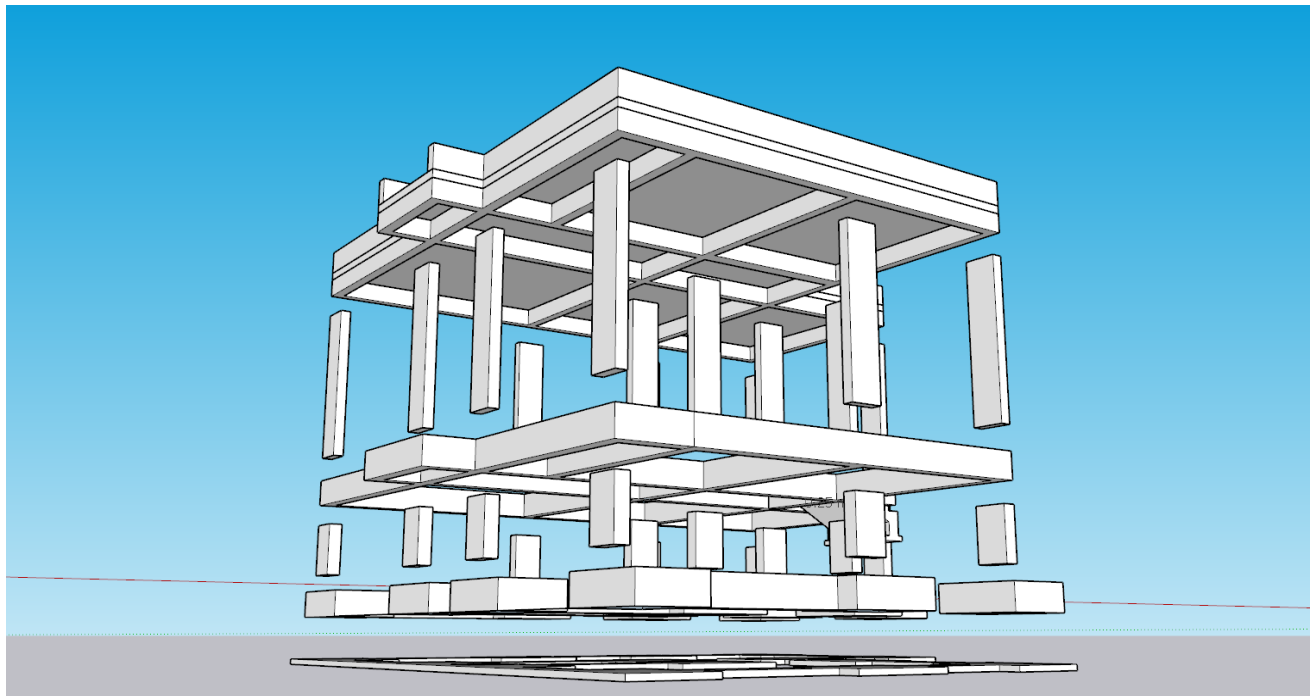
- Selected Tie Spacing: Use $\emptyset$ 8 mm ties @ 150 mm c/c (Conservative & Practical).

3. Design Summary & Conclusion

Component / Requirement	Designed Provision	Status / Notes
Column Dimensions	200 mm x 600 mm x 3000 mm	Adequate
Main Reinforcement	6 $\emptyset$ 16 mm ($A_{st} = 1206.4 \text{ mm}^2$)	$\rho = 1.005\%$ (Satisfies ACI)
Tie Reinforcement	$\emptyset$ 8 mm @ 150 mm c/c	Satisfies spacing limit ($\leq 200\text{mm}$)
Design Axial Load (P_u)	400.0 kN	Factored load
Design Axial Capacity (ϕP_n)	1733.7 kN	Safety Margin: 4.33x
Overall Design Status	PASS / STRUCTURALLY SAFE	Fully compliant with ACI 318-19

Structural Element Design

3-FOUNDATION



STRUCTURAL DESIGN REPORT

Reinforced Concrete Rectangular Isolated Footing Design
Conforming to ACI 318-19 Standards

1. Design Input Parameters

Parameter Description	Symbol	Value	Unit / Standard
Service Axial Load	P_service	300.0	kN
Factored Axial Load (1.4D)	P_u	420.0	kN
Allowable Soil Bearing Capacity	q_allow	200.0	kN/m²
Column Dimensions (Width x Length)	c1 x c2	250 x 650	mm
Specified Concrete Compressive Strength	f'c	28.0	MPa
Rebar Yield Strength	f_y	420.0	MPa
Main Reinforcement Bar Diameter	d_b	16	mm
Specified Clear Concrete Cover	c_c	75	mm (ACI 318-19 20.5.1.3)

2. Footing Proportioning & Geometry

To ensure uniform soil pressure distribution and equal cantilever projection in both directions, the difference in footing length and width is made equal to the difference in column dimensions:

- **Column Dimension Difference:** $c_2 - c_1 = 0.65 \text{ m} - 0.25 \text{ m} = 0.40 \text{ m}$
- **Required Area:** $A_{req} = P_{service} / q_{allow} = 300 / 200 = 1.50 \text{ m}^2$
- **Chosen Geometry:** Width (B) = 1.20 m, Length (L) = 1.80 m, Thickness (H) = 0.40 m (400 mm)
- **Provided Area:** $A_{prov} = 1.30 \times 1.70 = 2.21 \text{ m}^2$ ($> 1.50 \text{ m}^2$ - OK)
- **Ultimate Net Soil Pressure:** $q_u = P_u / A_{prov} = 420 / 2.21 = 190.05 \text{ kN/m}^2$
- **Effective Depth (d):** $d = 400 - 75 \text{ (cover)} - 16 \text{ (bar dia)} = 309 \text{ mm}$ (Adopted $d = 300 \text{ mm}$ for design)

3. Structural Safety Checks (ACI 318-19)

3.1 One-Way Shear Capacity Check

Critical section for one-way shear is located at distance $d = 0.30 \text{ m}$ from column face.

- **Cantilever Projection (L-dir):** $x = (1.70 - 0.65) / 2 = 0.525 \text{ m}$
- **Shear Demand (V_u1):** $V_{u1} = q_u \times B \times (x - d) = 190.05 \times 1.30 \times (0.525 - 0.30) = 55.59 \text{ kN}$
- **Concrete Shear Strength (ϕV_c):** $\phi V_c = 0.75 \times (1/6) \times \sqrt{f'c} \times B \times d = 0.75 \times (1/6) \times \sqrt{(28)} \times$

$$1300 \times 300 \times 10^{-3} = 257.96 \text{ kN}$$

- **Status: SAFE ($\phi V_c = 257.96 \text{ kN} > V_{u1} = 55.59 \text{ kN}$, D/C Ratio = 0.22)**

3.2 Two-Way (Punching) Shear Capacity Check

Critical section perimeter (b_0) is located at distance $d/2 = 0.15 \text{ m}$ from column faces.

- **Critical Perimeter (b_0):** $b_0 = 2 \times [(250 + 300) + (650 + 300)] = 3,000 \text{ mm}$
- **Punching Area:** $A_{\text{punc}} = 0.55 \times 0.95 = 0.5225 \text{ m}^2$
- **Punching Shear Demand (V_{u2}):** $V_{u2} = P_u - (q_u \times A_{\text{punc}}) = 420 - (190.05 \times 0.5225) = 320.70 \text{ kN}$

• **Concrete Punching Capacity (ϕV_c):** $\phi V_c = 0.75 \times 0.33 \times \sqrt{f_c} \times b_0 \times d = 0.75 \times 0.33 \times \sqrt{(28)} \times 3000 \times 300 \times 10^{-3} = 1,178.00 \text{ kN}$

- **Status: SAFE ($\phi V_c = 1,178.00 \text{ kN} > V_{u2} = 320.70 \text{ kN}$, D/C Ratio = 0.27)**

3.3 Bending Moment & Reinforcement

Critical section for bending is at the face of the column.

- **Maximum Bending Moment (M_u):** $M_u = q_u \times B \times (x^2 / 2) = 190.05 \times 1.30 \times (0.525^2 / 2) = 34.05 \text{ kN}\cdot\text{m}$
- **Minimum Reinforcement Ratio (ACI 318-19 24.4.3.2):** $A_{s,\text{min}} = 0.0018 \times B \times H = 0.0018 \times 1000 \times 400 = 720 \text{ mm}^2/\text{m}$
- **Provided Reinforcement:** 7 Ø 16 mm per meter ($A_{s,\text{provided}} = 1,407 \text{ mm}^2/\text{m} > 720 \text{ mm}^2/\text{m}$ - OK)

4. Summary of Final Design Recommendations

Component	Design Detail / Value	Specification
Footing Plan Dimensions	1.20 m x 1.80 m	Rectangular shape, centered
Footing Thickness (H)	0.40 m (400 mm)	Effective depth $d = 300 \text{ mm}$
Concrete Clear Cover	75 mm	Cast against and permanently exposed to earth
Long Direction Steel (L=1.70m)	7 Ø 16 mm / meter (10 bars total)	Placed along B-direction, spaced @ 140 mm
Short Direction Steel (B=1.30m)	7 Ø 16 mm / meter (12 bars total)	Placed along L-direction, spaced @ 140 mm
Concrete Grade	$f_c = 28 \text{ MPa}$	Normal weight concrete
Steel Grade	$f_y = 420 \text{ MPa}$	Grade 60 deformed rebar

AL FARSHAH PHCC EXTENSION YEMEN

Engineering
Services Unit

2026

March 2026

YEMEN FLECS Engineering
Consulting

Email - yahyaalgysi@gmail.com

Mobile _ 00967-- 777800603



AL FARSHAH PHCC EXTENSION -- Tur Albahah - Lahij Governorate

This report was
prepared for

