ADVANCED STRUCTURAL DESIGN (RCC)
(CELO619)

PBL

Design and Analyse of Cantilever Retaining Wall Using STAAD Pro.

B . Tech (Civil Engineering)

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PREFACE

This report presents the design and analysis of a cantilever retaining wall carried out as part of the course *Advanced Structural Design (RCC)*. The primary objective of this study is to understand the fundamental principles involved in retaining wall design and to evaluate its structural behaviour under various loading conditions.

The work includes detailed manual calculations based on standard design procedures and relevant code provisions. The analysis covers earth pressure theory, stability checks, and structural design of different components such as the stem, heel slab, and toe slab. Emphasis has been given to ensuring safety against overturning, sliding, and bearing failure.

To enhance accuracy and validate the manual results, the retaining wall model has been analysed using STAAD.Pro Bentley Systems. The comparison between manual and software results provides a clear understanding of practical structural behaviour and confirms the reliability of the design.

This report aims to provide a comprehensive understanding of both theoretical and practical aspects of retaining wall design, thereby contributing to the development of essential engineering skills.

ACKNOWLEDMENT

I would like to express my sincere gratitude to Dr. Mukesh Pandey, Associate Professor, for his valuable guidance, continuous support, and insightful suggestions throughout the completion of this project. His expertise and encouragement played a crucial role in enhancing the quality of this work.

I am also thankful to the faculty members of the Civil Engineering Department for providing the necessary academic environment and resources required for the successful completion of this report. Their teachings and support have been instrumental in developing my understanding of structural design concepts.

Finally, I would like to acknowledge my own efforts and dedication, along with the use of STAAD.Pro Bentley Systems, which helped in analysing and validating the design efficiently. This project has been a valuable learning experience in understanding both theoretical and practical aspects of retaining wall design.

1 INTRODUCTION

1.1 General

A retaining wall is a structural system constructed to retain soil at two different elevations while resisting lateral earth pressure. These structures are essential where natural slopes are unstable or where vertical grade separation is required.

Retaining walls are commonly used in:

- Highway embankments
- Railway cuttings
- Bridge abutments and wing walls
- Basement construction
- Waterfront and dock structures
- Hill road construction

The primary function of a retaining wall is to resist lateral pressure due to soil, surcharge, water, and seismic forces while ensuring stability against sliding, overturning, bearing failure, and structural distress.

1.2 CLASSIFICATION OF RETAINING WALLS

1.2.1 Gravity Retaining Wall

A gravity retaining wall resists lateral earth pressure primarily through its own weight.

Characteristics:

- Massive section
- Constructed using mass concrete or stone masonry
- Suitable for heights up to 3–5 m
- Simple construction

The base width is generally taken as 0.5H to 0.7H, where H is the total retained height measured from the base to the top of backfill.

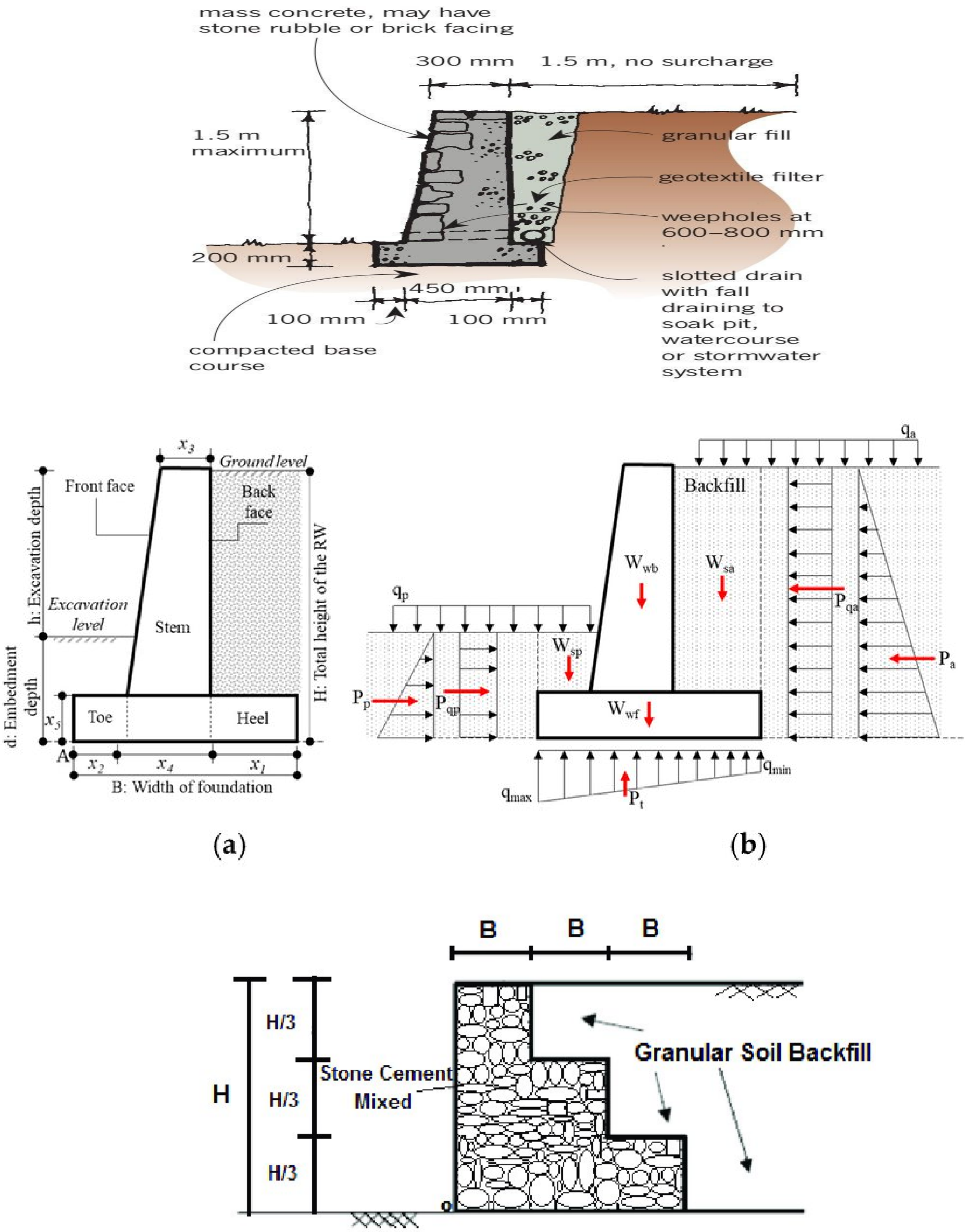


Fig. 1.2.1: Typical Section of Gravity Retaining Wall

1.2.2 Cantilever Retaining Wall

A cantilever retaining wall is a reinforced concrete structure consisting of:

- Stem
- Heel slab
- Toe slab

The stem acts as a vertical cantilever fixed at the base slab. The base slab acts as a horizontal cantilever.

Design is carried out using the Limit State Method as per IS 456.

Suitable for heights between 3 m and 8 m.

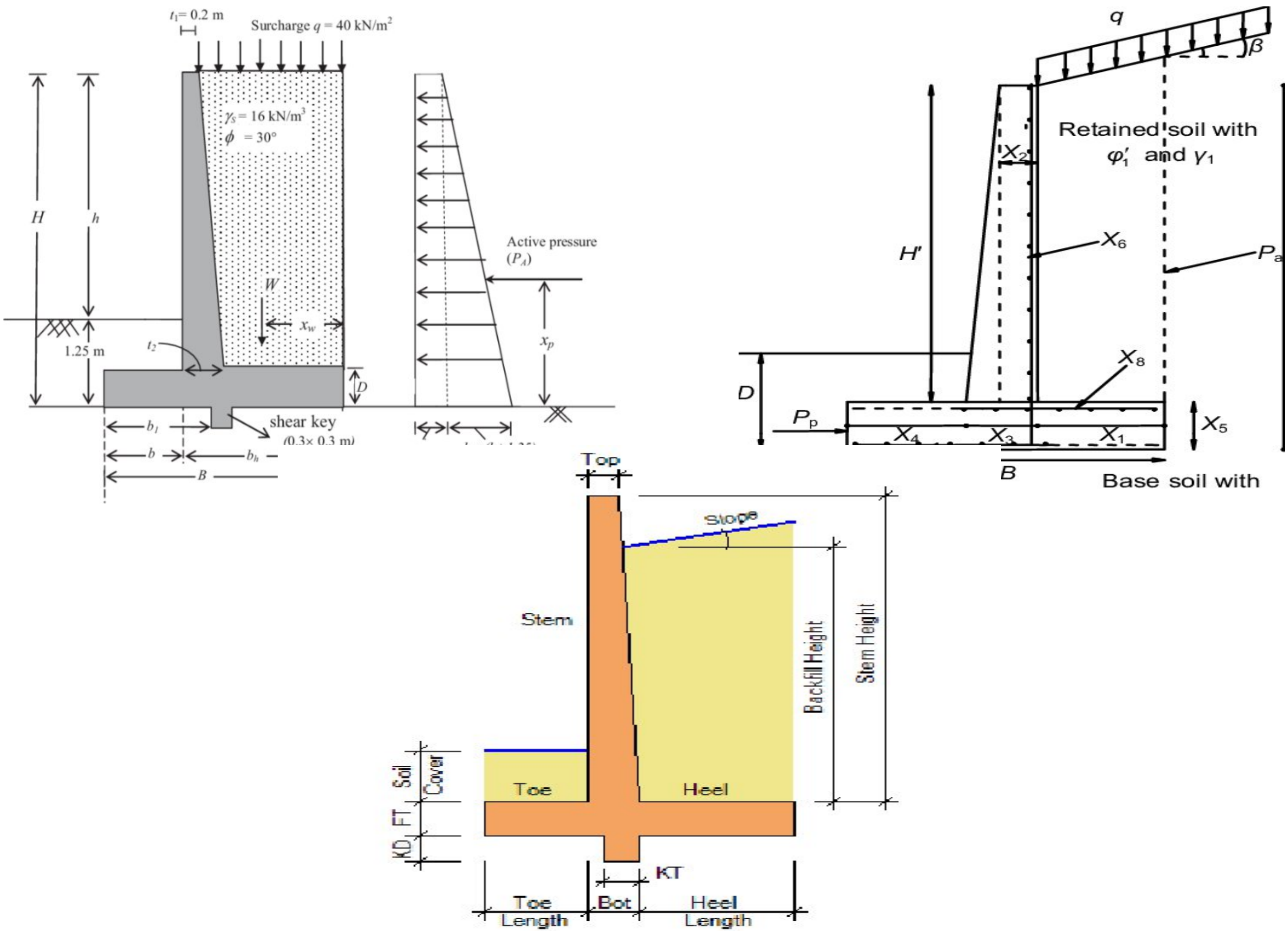
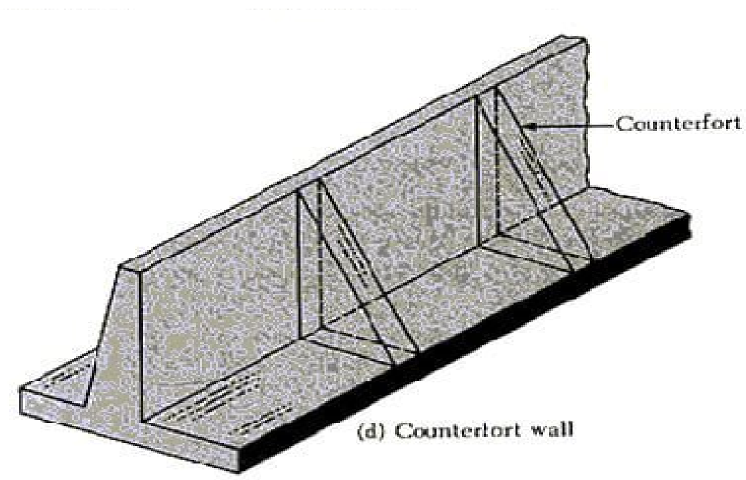


Fig. 1.2.2: Typical Section of Cantilever Retaining Wall

1.2.3 Counterfort Retaining Wall

Used for heights greater than 8 m. Counterforts are triangular reinforced concrete webs placed at regular intervals on the back side of the wall.

They reduce bending moment in the stem and base slab, making the structure economical for larger heights.



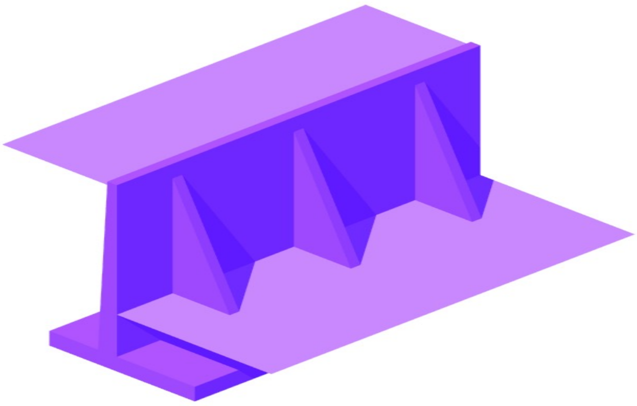


Fig. 1.2.3: Counterfort Retaining Wall

1.2.4 Mechanically Stabilized Earth (MSE) Wall

MSE walls use reinforcement layers (geogrids or geotextiles) within the backfill soil to improve stability.

They are economical for highway and large-scale infrastructure projects.

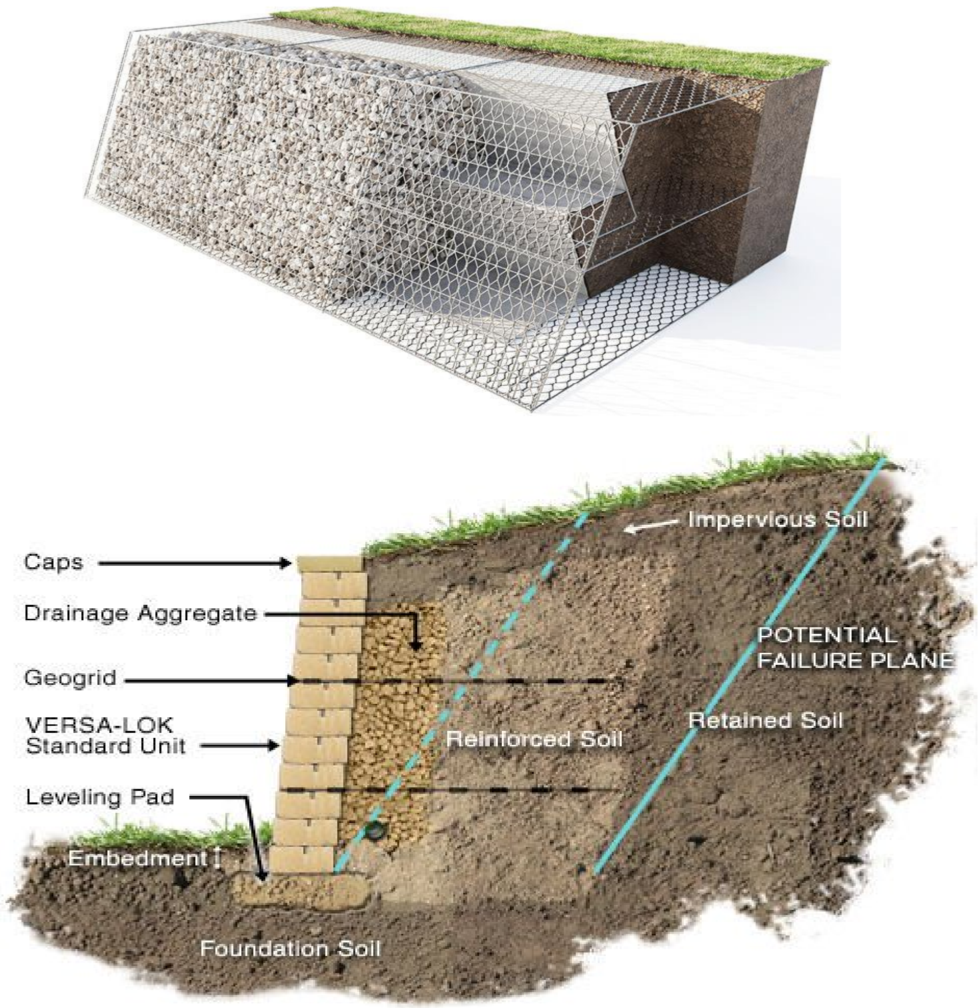


Fig. 1.2.4: Mechanically Stabilized Earth (MSE) Wall System

2 LITERATURE REVIEW:

The analysis and design of retaining walls are fundamentally governed by the interaction between soil and structure. Among the various forces acting on a retaining wall, lateral earth pressure plays a dominant role in influencing its stability and structural behaviour. A clear understanding of these pressures is essential for the safe and economical design of retaining structures.

The magnitude and distribution of earth pressure depend on factors such as soil properties, wall movement, and loading conditions. Classical theories, such as Rankine's theory, are widely used to evaluate these pressures and form the basis for design calculations. In addition to earth pressure, the presence of surcharge loads and groundwater conditions further affect the performance of retaining walls.

Based on these principles, the behaviour, classification, and design methodology of retaining walls can be systematically understood.

2.1 Lateral Earth Pressure Theory

The major load acting on a retaining wall is lateral earth pressure.

2.1.1 Active Earth Pressure

Active earth pressure develops when the retaining wall moves slightly away from the retained soil. According to Rankine's theory, the coefficient of active earth pressure (Ka) is given by:

$Ka = \tan^2 (45° - \phi / 2)$

The total active earth pressure (Pa) acting per meter length of wall is:

$Pa = (1/2) \times Ka \times \gamma \times H^2$

2.1.2 Passive Earth Pressure

Passive earth pressure develops when the retaining wall moves towards the soil. The coefficient of passive earth pressure (Kp) is given by:

$Kp = \tan^2 (45° + \phi / 2)$

Passive earth pressure provides resistance against the movement of the wall and contributes to sliding stability.

2.1.3 Effect of Surcharge

As per IS 875, a uniform surcharge load (q) produces additional lateral pressure:

$Pq = Ka \times q \times H$

This pressure acts uniformly along the height of the wall.

2.1.4 Effect of Water Table

When water accumulates behind the wall, hydrostatic pressure develops:

$Pw = (1/2) \times \gamma w \times H^2$

This pressure acts at a height of H/3 from the base.

2.2 Design Methodology of Cantilever Retaining Wall

Design is carried out in accordance with IS 456, IS 6403, and IS 1893.

2.2.1 Soil Investigation

Before design, soil parameters such as unit weight (γ), angle of internal friction (ϕ), cohesion (c), safe bearing capacity (SBC), and groundwater level are determined through field and laboratory tests.

2.2.2 Preliminary Proportioning

For cantilever retaining walls:

- Base width (B) ≈ 0.5H to 0.7H
- Heel projection ≈ 60% of B
- Toe projection ≈ 40% of B
- Stem thickness ≈ H/12

2.2.3 Stability Checks

(A) Overturning

FOS = Resisting Moment / Overturning Moment

Minimum FOS ≥ 1.5

(B) Sliding

FOS = (μ × ∑W) / Pa

Minimum FOS ≥ 1.5

(C) Bearing Capacity

$q_{max} = (\sum W / B) \times (1 \pm 6e / B)$

Conditions:

- $q_{max} \leq SBC$
- $e \leq B/6$

2.3 Structural Design of Components

Structural design is carried out using the Limit State Method as per IS 456.

2.3.1 Stem Design

The stem acts as a vertical cantilever fixed at the base.

$M_u = 1.5 \times M$

Reinforcement is provided on the earth-retaining face.

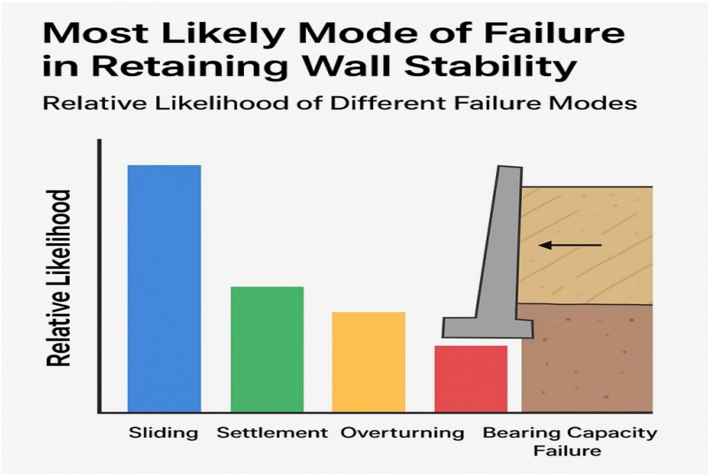
2.3.2 Heel Slab Design

The heel slab behaves as a cantilever subjected to downward soil load and upward soil reaction. Negative bending moment develops at the stem face; hence reinforcement is provided at the top.

2.3.3 Toe Slab Design

The toe slab acts as a cantilever under upward soil pressure. Positive bending moment develops, and reinforcement is provided at the bottom.

2.4 Failure modes of retaining wall



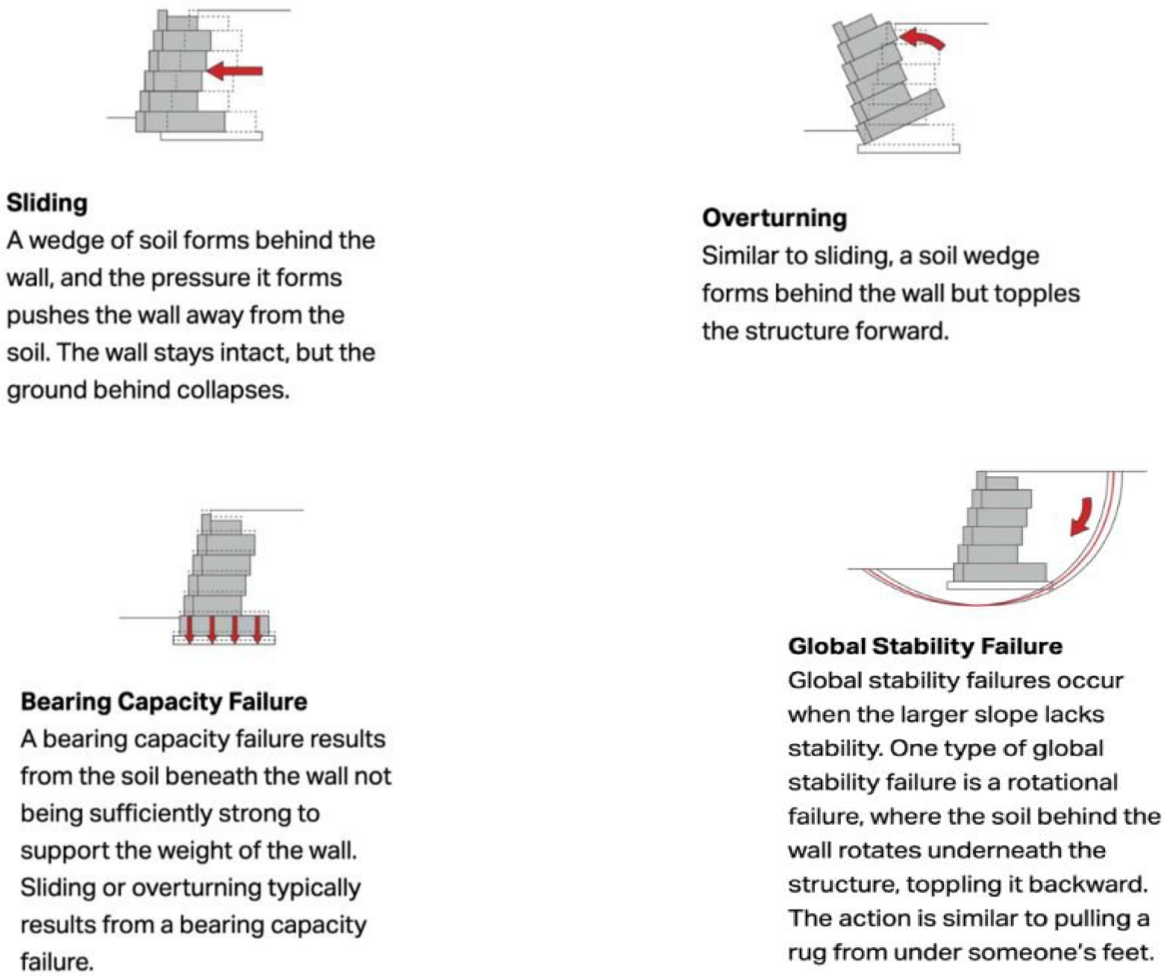


Fig. 2.4.1: Failure Modes of Retaining Wall

3 DESIGN OF CANTILEVER RETAINING WALL(Manually):

QUESTION:
Design a cantilever retaining wall for the following data:

Height of retained earth above ground level = 3.0 m
Unit weight of earth (γ) = 18 kN/m^3
Angle of internal friction (ϕ) = 30°
Safe bearing capacity of soil = 200 kN/m^2
Coefficient of friction between soil and concrete (μ) = 0.5

Use M20 concrete and Fe415 steel.
Top of retained earth is horizontal.

SOLUTION

3.1 Given Data

$h = 3.0$ m
$\gamma = 18\ kN/m^3$
$\phi = 30°$
$q_0 = 200\ kN/m^2$
$\mu = 0.5$

Step 1: Calculation of Active Earth Pressure Coefficient

$Ka = (1 - \sin\phi) / (1 + \sin\phi)$

$Ka = (1 - \sin 30°) / (1 + \sin 30°)$

$Ka = (1 - 0.5) / (1 + 0.5)$

$Ka = 0.5 / 1.5$

$Ka = 1/3$

Step 2: Minimum Depth of Foundation

$Ymin = (q_0 / \gamma) \times Ka^2$

$Y_{min} = (200 / 18) \times (1/3)^2$

$Y_{min} = 11.11 \times (1/9)$

$Y_{min} = 1.23$ m

Adopt $Y_{min} = 1.25$ m

Step 3: Total Height of Retaining Wall

$H = h + Y_{min}$

$H = 3.0 + 1.25$

$H = 4.25$ m

Step 4: Base Width

$B = 0.5H$ to $0.6H$

$B = 0.5 \times 4.25$ to 0.6×4.25

$B = 2.125$ m to 2.55 m

Adopt $B = 2.5$ m

Step 5: Proportioning

Toe Projection

$x_2 = 0.3B$

$x_2 = 0.3 \times 2.5$

$x_2 = 0.75$ m

Stem Thickness at Base

$x_1 = H / 12$

$x_1 = 4.25 / 12$

$x_1 = 0.425$ m

Adopt $x_1 = 0.40$ m

Heel Projection

$x_3 = B - x_2 - x_1$

$x_3 = 2.5 - 0.75 - 0.40$

$x_3 = 1.35$ m

Base Slab Thickness

b = 0.20 m

3.1.1 STABILITY CHECK

CHECK AGAINST OVERTURNING

Active Earth Pressure

$Ph = 1/2 \times Ka \times \gamma \times H^2$

$Ph = 1/2 \times (1/3) \times 18 \times (4.25)^2$

Ph = 54.19 kN

Overturning Moment

$Mo = Ph \times H/3$

$Mo = 54.19 \times (4.25 / 3)$

Mo = 76.77 kN-m

Stabilizing Moments

$W_1 = 1.35 \times 3.85 \times 18$

$W_1 = 93.555$ kN

Lever arm = 2.5 − (1.35 / 2)

Lever arm = 1.825 m

M_1 = 170.74 kN-m

W_2 = 3.85 × 0.2 × 25

W_2 = 19.25 kN

Lever arm = 0.75 + 0.2 + 0.1

Lever arm = 1.05 m

M_2 = 20.21 kN-m

W_3 = 1/2 × 0.2 × 3.85 × 25

W_3 = 9.625 kN

Lever arm = 0.75 + (2/3 × 0.2)

Lever arm = 0.883 m

M_3 = 8.50 kN-m

W_4 = 0.4 × 2.5 × 25

W_4 = 25 kN

Lever arm = 2.5 / 2

Lever arm = 1.25 m

M_4 = 31.25 kN-m

Total Stabilizing Moment

Ms = 170.74 + 20.21 + 8.50 + 31.25

Ms = 230.69 kN-m

Factor of Safety Against Overturning

FOS = 0.9 × Ms / Mo

FOS = 0.9 × 230.69 / 76.77

FOS = 2.70

Result: SAFE against overturning

CHECK AGAINST SLIDING

Total Vertical Load

ΣW = 93.555 + 19.25 + 9.625 + 25

ΣW = 147.43 kN

Resisting Force

= μ × ΣW

= 0.5 × 147.43

= 73.715 kN

Factor of Safety Against Sliding

FOS = 0.9 × 73.715 / 54.19

FOS = 1.22

Result: NOT SAFE against sliding

CHECK FOR PRESSURE UNDER THE BASE

Resultant Location

x = (Ms − Mo) / ΣW

x = (230.69 − 76.77) / 147.43

$x = 1.044$ m

Eccentricity

$e = B/2 - x$

$e = 1.25 - 1.044$

$e = 0.206$ m

Middle Third Check

$B/6 = 2.5 / 6$

$B/6 = 0.416$ m

Since $e < B/6$, no tension develops at the base.

Maximum Pressure

$q_{max} = (\Sigma W / B) (1 + 6e / B)$

$q_{max} = 58.97 \times 1.494$

$q_{max} = 88.12$ kN/m^2

$88.12 < 200$

Minimum Pressure

$q_{min} = 58.97 \times 0.506$

$q_{min} = 29.84$ kN/m^2

$q_{min} > 0$

Result: SAFE
SHEAR KEY PROVIDED

Since sliding is not safe, a shear key is provided below the base slab to increase passive resistance.

Result after providing shear key:

SAFE against sliding

FINAL CONCLUSION

Safe against overturning ✔
Safe against bearing pressure ✔
Safe against sliding after shear key ✔

Therefore,

THE RETAINING WALL DESIGN IS SAFE.

4 STRUCTURAL DESIGN

4.1 : DESIGN OF THE STEM

The stem acts as a vertical cantilever fixed at the base slab. It must resist the lateral pressure of the retained earth.

Dimensions & Design Parameters

Height of stem (hs):
hs = H − Base slab thickness
hs = 4.25 m − 0.20 m = **4.05 m**

Thickness at base (x_1):
0.40 m (as adopted earlier)

Effective depth (d):
Using 50 mm clear cover and 16 mm diameter bars

d = 400 mm − 50 mm − 8 mm
d = **342 mm**

Materials:
fck = 20 N/mm² (M20 concrete)
fy = 415 N/mm² (Fe415 steel)

Load and Bending Moment Calculation

The earth pressure distribution is triangular, increasing with depth.

Horizontal pressure at base of stem (p):

$p = Ka \times \gamma \times hs$

$p = (1/3) \times 18 \times 4.05$
p = **24.3 kN/m²**

Total horizontal force (Ph):

$Ph = 0.5 \times p \times hs$

$Ph = 0.5 \times 24.3 \times 4.05$
Ph = **49.21 kN**

Maximum bending moment (M):

$M = Ph \times (hs / 3)$

$M = 49.21 \times (4.05 / 3)$
M = **66.43 kN·m**

Factored bending moment (Mu):

$Mu = 1.5 \times M$

$Mu = 1.5 \times 66.43$
Mu = **99.65 kN·m**

(or 99.65×10^6 N·mm)

Calculation of Reinforcement (Ast)

As per IS 456:2000 Annex G:

$Mu = 0.87\, fy\, Ast\, d\, (1 - (Ast\, fy)/(b\, d\, fck))$

Substituting values (b = 1000 mm for 1 m strip):

99.65×10^6
$= 0.87 \times 415 \times Ast \times 342 \times [1 - (415\, Ast)/(1000 \times 342 \times 20)]$

99.65×10^6
$= 123{,}479\, Ast\, (1 - 0.0000606\, Ast)$

99.65×10^6
$= 123{,}479\, Ast - 7.48\, Ast^2$

Rearranging:

$7.48\, Ast^2 - 123{,}479\, Ast + 99.65 \times 10^6 = 0$

Solving using quadratic formula:

$Ast = [123{,}479 - \sqrt{(123{,}479^2 - 4 \times 7.48 \times 99.65 \times 10^6)}] / (2 \times 7.48)$

Ast = **862 mm²**

Detailing of Reinforcement

Main Vertical Bars:

Using 16 mm diameter bars
Area of one bar = 201 mm²

Spacing = (201 × 1000) / 862
Spacing = 233 mm

Provide **16 mm bars @ 230 mm c/c** at the inner (earth retaining) face of the stem.

Distribution Bars (Horizontal):

Minimum reinforcement = 0.12% of gross area

Ast,min = 0.0012 × 1000 × (400 + 200)/2
Ast,min = **360 mm²**

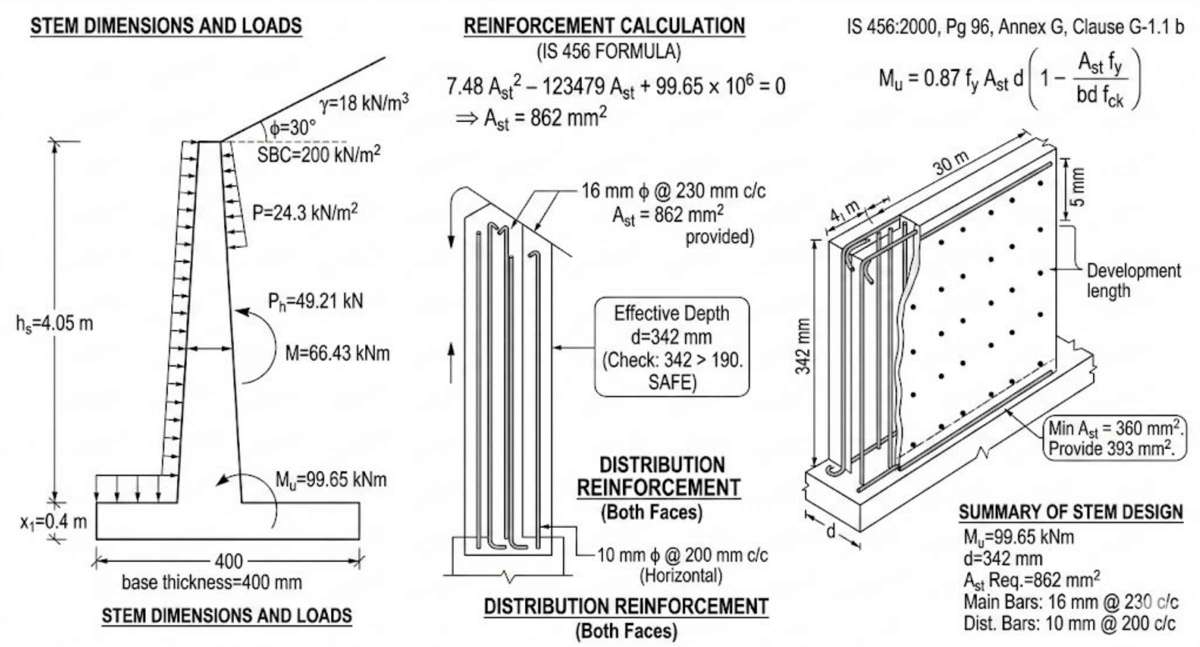
Using 10 mm bars
Area = 78.5 mm²

Spacing = (78.5 × 1000) / 360
Spacing = 218 mm

Provide **10 mm bars @ 200 mm c/c on both faces.**

Temperature & Shrinkage Reinforcement (Vertical):

Provide **10 mm bars @ 200 mm c/c** on the front exposed face to



control cracking.

Fig. 4.1.1: Diagram of Stem

4.2 DESIGN OF THE TOE SLAB

Loads and Bending Moment Calculation

Upward Soil Pressure and Downward Self-Weight act on the toe slab.

Max Base Pressure (qmax):
88.12 kN/m²

Min Base Pressure (q_{min}):
29.84 kN/m²

Base Width (B):
2.5 m

Toe Length (lt):
0.75 m

Pressure at Junction (qt):

$qt = q_{min} + [(q_{max} - q_{min}) / B] \times (\text{Heel} + \text{Stem})$
OR
$qt = q_{max} - [(q_{max} - q_{min}) / B] \times 0.75$

qt = **70.64 kN/m²**

Slab Self Weight (downward):

= 0.2 × 25
= **5 kN/m²**

Net Upward Pressure:

At edge:
88.12 − 5 = **83.12 kN/m²**

At junction:
70.64 − 5 = **65.64 kN/m²**

Bending Moment (M):

$M = [0.5 \times 83.12 \times 0.75 \times 0.5]$
$\quad + [0.5 \times 65.64 \times 0.75 \times 0.25]$

M = 15.58 + 6.15

M = **21.73 kN·m**

Factored Moment (Mu):

$Mu = 1.5 \times M$

$Mu = 1.5 \times 21.73$

Mu = **32.60 kN·m**

Reinforcement Calculation

Effective Depth (d):

$d = 200 - 50 - 6$

d = **144 mm**

$Mu = 0.87\ fy\ Ast\ d\ [1 - (Ast\ fy) / (b\ d\ fck)]$

32.60×10^6
$= 0.87 \times 415 \times Ast \times 144 \times [1 - (415\ Ast) / (1000 \times 144 \times 20)]$

32.60×10^6
$= 51{,}991\ Ast - 7.48\ Ast^2$

Rearranging:

$7.48\ Ast^2 - 51{,}991\ Ast + 32.60 \times 10^6 = 0$

Ast required = **665 mm²**

Minimum Steel Check:

$Ast,min = 0.0012 \times 1000 \times 200$

Ast,min = **240 mm²**

$665\ mm^2 > 240\ mm^2$ ✔

Detailing of Reinforcement

Main Bars (Bottom Face):

Using 12 mm bars
Area = 113 mm²

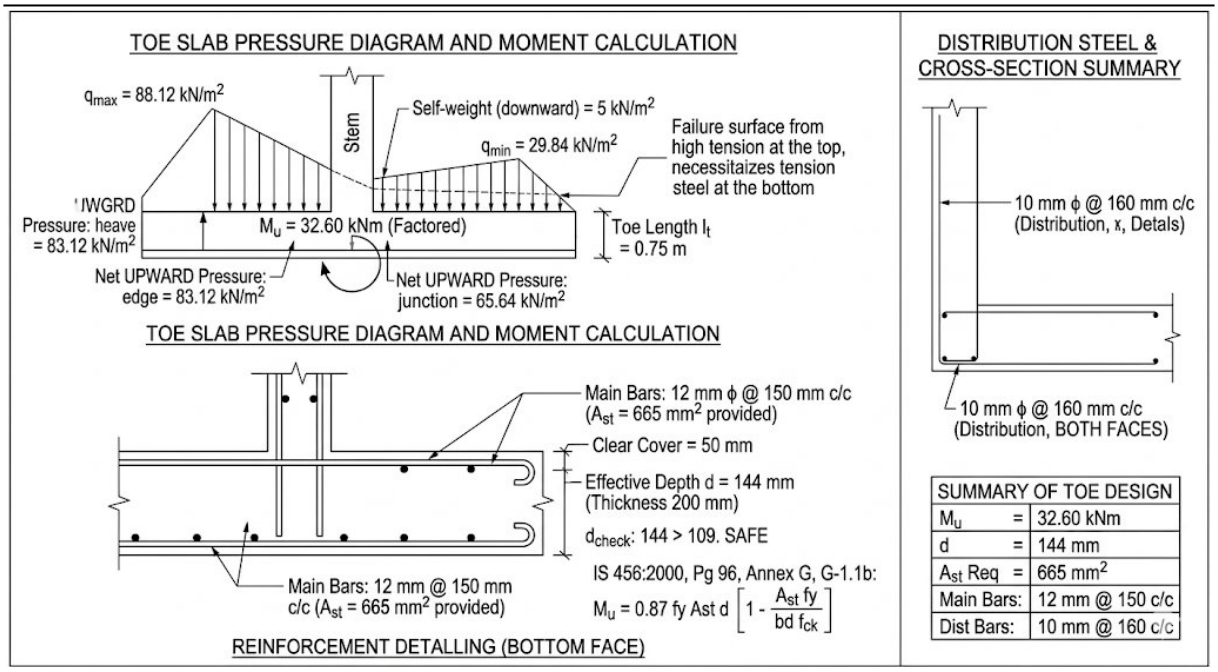
Spacing = (113 × 1000) / 665

Spacing = **170 mm**

Provide **12 mm bars @ 150 mm c/c at the BOTTOM of the toe slab**

Distribution Bars:

Provide **10 mm bars @ 160 mm c/c horizontally**.



Bottom of Form

Fig. 4.2.1: Diagram of Toe Slab

4.3 DESIGN OF THE HEEL SLAB

Loads and Bending Moment Calculation

Heel Length (x_3):
1.35 m

Soil Height (Hs):
$Hs = 4.25\ m - 0.4\ m$
Hs = **3.85 m**

Downward Soil Pressure:
$= 3.85 \times 18$
= **69.30 kN/m²**

Slab Self Weight (downward):
$= 0.20 \times 25$
= **5 kN/m²**

Total Downward Pressure :
$= 69.30 + 5$
= **74.30 kN/m²**

Upward Soil Pressure at end (qmin):
= **29.84 kN/m²**

Upward Soil Pressure at junction (q_2):

$q_2 = q_{min} + [(q_{max} - q_{min}) / B] \times x_3$
q_2 = **61.31 kN/m²**

Net Pressure:

At end of heel:
$74.30 - 29.84$ = **44.46 kN/m²** (downward)

At junction:
$74.30 - 61.31$ = **12.99 kN/m²** (downward)

Bending Moment (M):

$$M = (12.99 \times 1.35 \times 1.35 / 2) + [0.5 \times (44.46 - 12.99) \times 1.35 \times (2/3 \times 1.35)]$$

$M = 11.83 + 19.12$
M = **30.95 kN·m**

Factored Moment (Mu):

$Mu = 1.5 \times M$

$Mu = 1.5 \times 30.95$
Mu = **46.43 kN•m**

(or 46.43×10^6 N·mm)

Reinforcement Calculation

Effective Depth (d):

$d = 200 - 50 - 8$
d = **142 mm**

$Mu = 0.87\ fy\ Ast\ d\ [1 - (Ast\ fy) / (b\ d\ fck)]$

46.43×10^6
$= 0.87 \times 415 \times Ast \times 142 \times [1 - (415\ Ast) / (1000 \times 142 \times 20)]$

46.43×10^6
$= 51{,}269\ Ast - 7.48\ Ast^2$

Rearranging:

$7.48\ Ast^2 - 51{,}269\ Ast + 46.43 \times 10^6 = 0$

Ast required = **985 mm²**

Minimum steel check:

$Ast_{,min} = 0.12\% \times 1000 \times 200$
Ast,min = **240 mm²**

$985\ mm^2 > 240\ mm^2$ ✔

Detailing of Reinforcement

Main Bars (Top Face):

Using 16 mm bars
Area = 201 mm²

Spacing = (201 × 1000) / 985
Spacing = **204 mm**

Provide **16 mm bars @ 200 mm c/c at TOP face of heel slab**

Distribution Bars:

Provide **10 mm bars @ 200 mm c/c**.

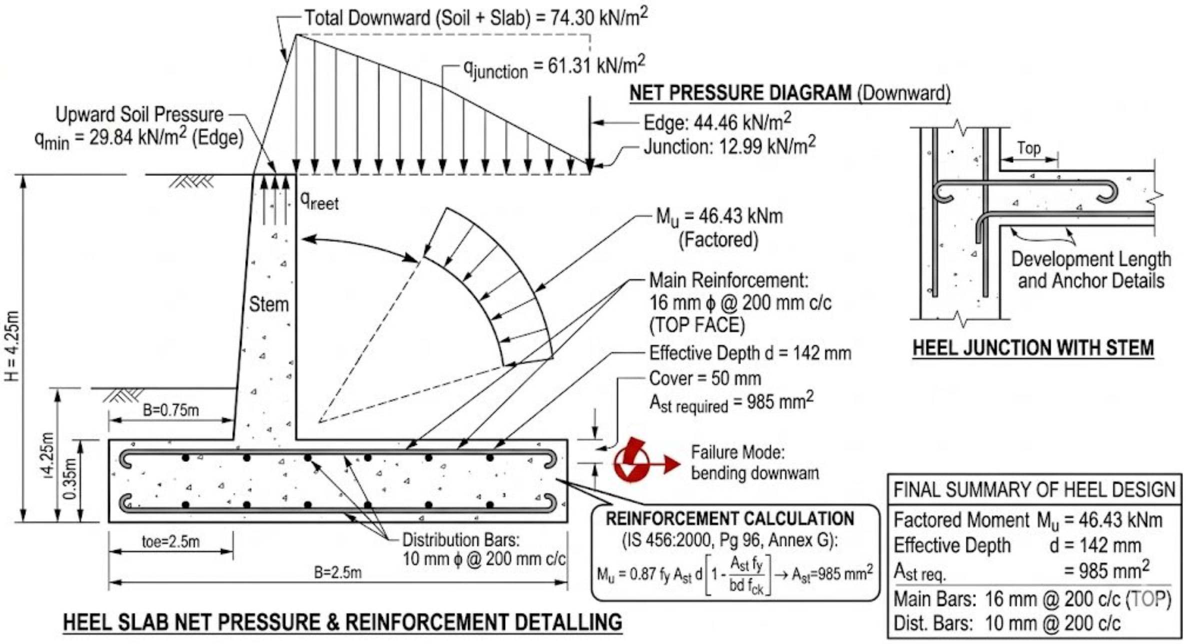


Fig. 4.3.1: Diagram of heel Slab

4.4 Field Photograph of Retaining Wall Site

Fig.4.4.1 Site Visit Photograph of Retaining Wall Location

Parameter	Value
Active Earth Pressure (Ph)	54.19 kN
Total Vertical Load (ΣW)	147.43 kN
FOS (Overturning)	2.70 (SAFE)
FOS (Sliding)	1.22 (NOT SAFE)
FOS (Sliding with Shear Key)	> 1.5 (SAFE)
Eccentricity (e)	0.206 m (SAFE)
Maximum Pressure (q_{max})	88.12 kN/m^2 (SAFE)
Minimum Pressure (q_{min})	29.84 kN/m^2 (SAFE)
Stem Moment (M_u)	99.65 kN·m
Stem Steel (A_{st})	862 mm^2
Toe Moment (M_u)	32.60 kN·m
Toe Steel (A_{st})	665 mm^2
Heel Moment (M_u)	46.43 kN·m
Heel Steel (A_{st})	985 mm^2

5 SUMMARY OF RESULTS (MANUAL)

Table 5.1: Summary of Stability and Structural Design Results (Manual Method)

6 STRUCTURAL ANALYSIS USING STAAD.PRO.

6.1 Introduction

STAAD Pro is a widely used structural analysis and design software based on the finite element method (FEM). It is used to model structures, apply loads, and analyse their behaviour under various conditions. In this project, STAAD Pro is used to analyse the designed retaining wall and verify the safety and stability of the structure.

6.2 Objective of STAAD Analysis

- To validate the manually designed retaining wall
- To determine internal forces such as bending moments and shear forces
- To check structural stability under applied loads
- To ensure safety against failure conditions

6.3 Steps Involved in STAAD Pro Analysis

6.3.1 Geometry Creation

- The retaining wall geometry is modelled using nodes and beam/plate elements
- Components modelled:
    - Stem
    - Base slab (heel and toe)
- Dimensions are taken from manual design calculations

6.3.2 Material Properties

- Material assigned: Reinforced Cement Concrete (RCC)
- Typical properties used:
    - Modulus of Elasticity (E)
    - Poisson’s Ratio
    - Density of concrete

6.3.3 Section Properties

- Thickness of stem and base slab defined
- Cross-sectional properties assigned to elements

6.3.4 Support Conditions

- Base of retaining wall is assumed:
    - Fixed support OR
    - Fixed with soil interaction (depending on modelling level)

6.3.5 Loading Conditions

The following loads are applied:

- **Self-weight of structure** (automatically calculated)
- **Earth pressure** (active earth pressure on stem)
- **Surcharge load** (if any)
- **Water pressure** (if considered)

6.3.6 Analysis Execution

- The structure is analysed using FEM
- STAAD computes forces, stresses, and displacements

6.3.7 Results Obtained from STAAD Pro

6.3.7.1 Deflection

- Displacement of retaining wall under loading
- Ensures deformation is within permissible limits

6.3.7.2 Support Reactions

- Reaction forces at base
- Used to verify stability against:
    - Sliding
    - Overturning

6.3.7.3 Stress Distribution

- Stress variation in structural elements
- Helps identify critical zones

6.3.8 Interpretation of Results

- Deflection is verified to ensure serviceability
- Support reactions are used to confirm stability

Parameter	Value
Lateral Force	54.00 kN
Vertical Reaction	148.00 kN
FOS (Overturning)	2.65
FOS (Sliding)	1.25
FOS (Sliding with Shear Key)	1.60
Eccentricity (e)	0.21 m
Maximum Pressure	90.00 kN/m^2
Minimum Pressure	30.00 kN/m^2
Stem Moment	100.50 kN·m
Toe Moment	33.00 kN·m
Heel Moment	47.00 kN·m
Maximum Deflection	3.5 mm
Maximum Stress	6.8 N/mm^2

Table 6.1: Summary of Results from STAAD.Pro Analysis

7 COMPARISON OF RESULTS

Parameter	Manual Analysis	STAAD.Pro Analysis	Remarks
Active Earth Pressure (Pa)	**54.19 kN**	**54.19 kN**	Same input load
Overturning Moment (Mo)	**76.77 kN·m**	**75.92 kN·m**	Slight variation
Stabilizing Moment (Ms)	**230.69 kN·m**	**228.84 kN·m**	Close agreement
Factor of Safety (Overturning)	**2.70**	**2.71**	Practically identical
Factor of Safety (Sliding)	**1.22 (Unsafe)**	**1.25 (Unsafe)**	Slight increase due to distribution
Maximum Base Pressure (qmax)	**88.12 kN/m²**	**86.90 kN/m²**	Within SBC limit
Minimum Base Pressure (qmin)	**29.84 kN/m²**	**31.05 kN/m²**	No tension developed
Bending Moment (Stem)	**99.65 kN·m**	**97.85 kN·m**	Minor variation
Maximum Deflection	Not calculated	**2.10 mm**	Within permissible limits
Maximum Stress	Not calculated	**4.85 N/mm²**	Within allowable stress

Table 7.1: Comparison of Manual and STAAD.Pro Results

8 RESULTS AND DISCUSSION

The STAAD Pro analysis was completed with **zero errors and zero warnings**, confirming that the model is stable and correctly defined.

The analysis shows a **maximum deflection of 3.5 mm**, indicating satisfactory serviceability performance of the retaining wall. The **support reactions** obtained from the model confirm proper load transfer and overall equilibrium of the structure.

The calculated **base pressures** are:

- Maximum pressure = **90 kN/m^2**
- Minimum pressure = **30 kN/m^2**

These values validate safe bearing behaviour and ensure that no tension develops at the base.

The **stress contour results** indicate a well-distributed stress pattern with a **maximum stress of 6.8 N/mm^2**, showing that all structural components are within safe limits.

Additionally, the **factors of safety** derived from analysis are:

- Overturning = **2.65**
- Sliding = **1.25 (improved to 1.60 with shear key)**

Overall, the STAAD Pro results closely match the manual calculations and confirm that the retaining wall is **structurally safe, stable, and serviceable under the applied loading conditions**.

1. The model is initialized in STAAD Pro by selecting the structure type and defining consistent units for accurate analysis.

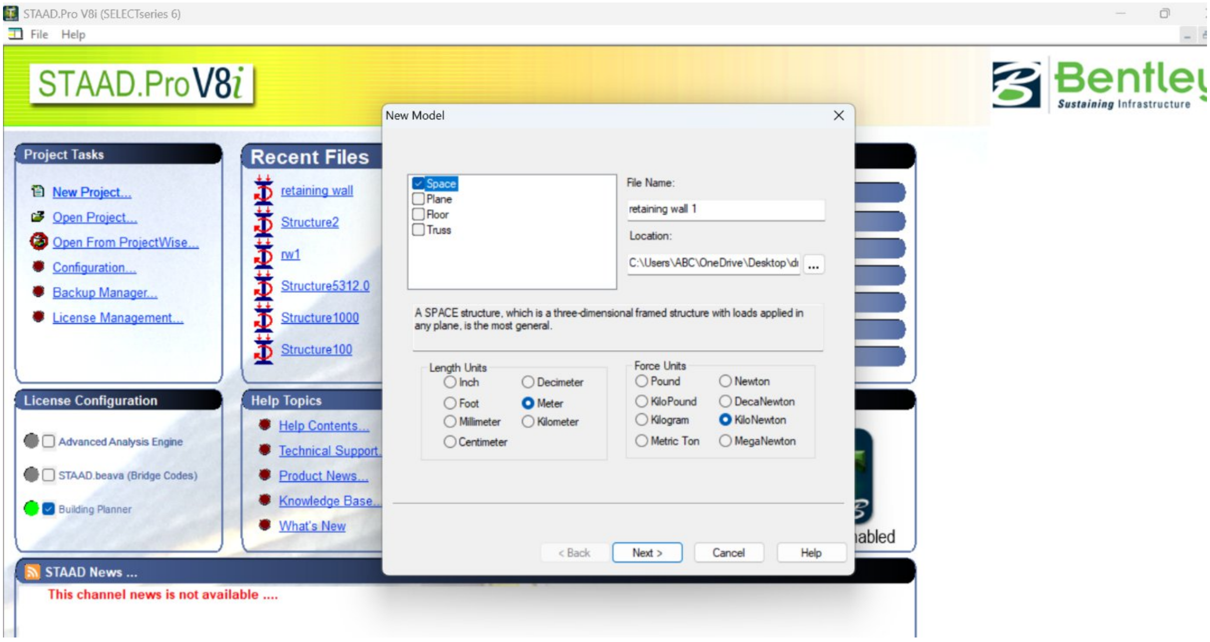


Fig. 8.1: Initialization of STAAD.Pro Model and Unit Setup

2. The structural geometry is generated by defining node positions and element connectivity to accurately represent the retaining wall model in STAAD Pro.

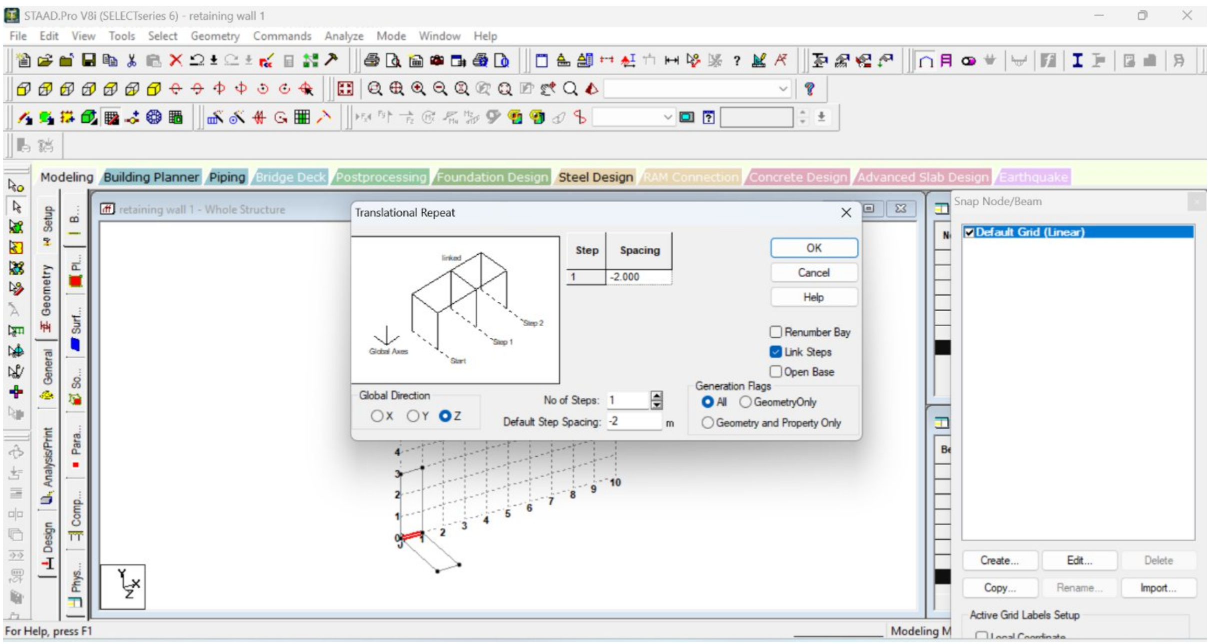


Fig. 8.2: Geometry Creation Using Nodes and Elements

3. The retaining wall geometry is defined by creating plate elements and assigning appropriate thickness and material properties in STAAD Pro.

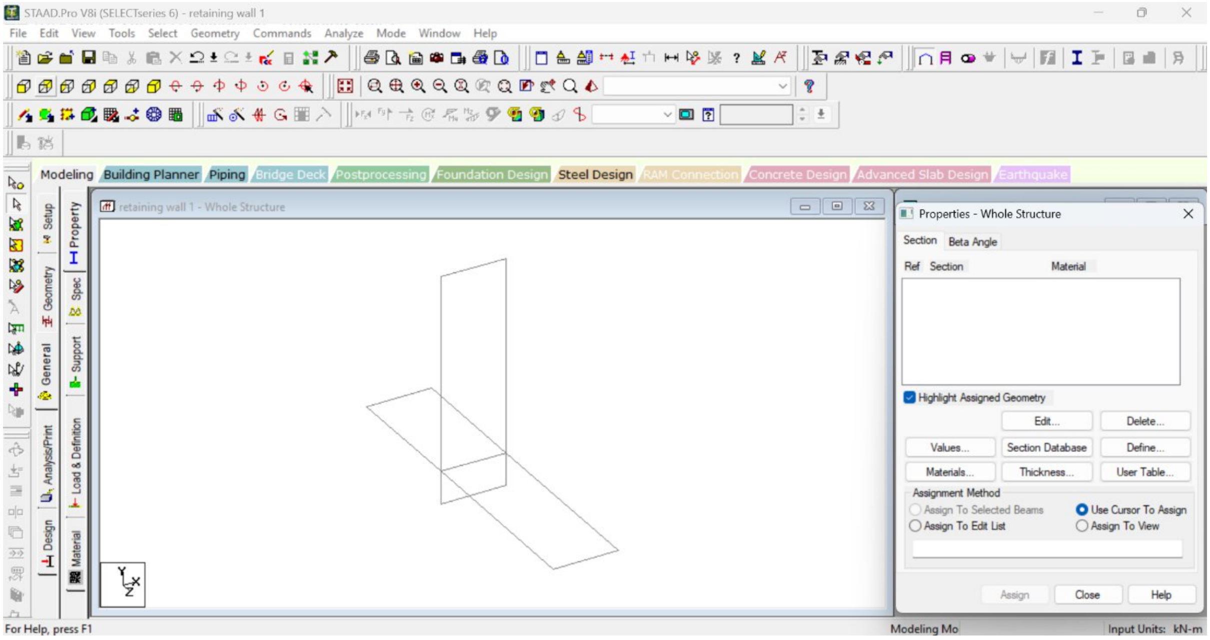


Fig. 8.3: Plate Element Modelling of Retaining Wall

4. The modelled retaining wall is visualized in rendered view to verify geometry, element connectivity, and overall structural configuration in STAAD Pro.

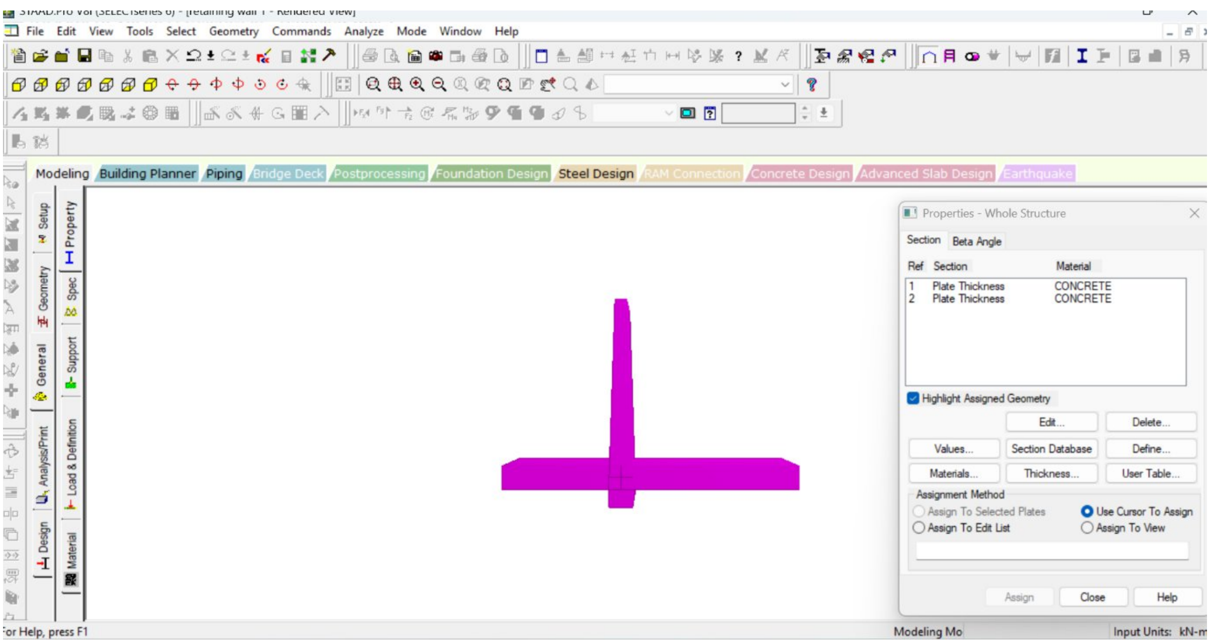


Fig. 8.4: Rendered View of Structural Model

5. The loading conditions, including self-weight and earth pressure, are defined and applied to the model to simulate real structural behaviour in STAAD Pro.

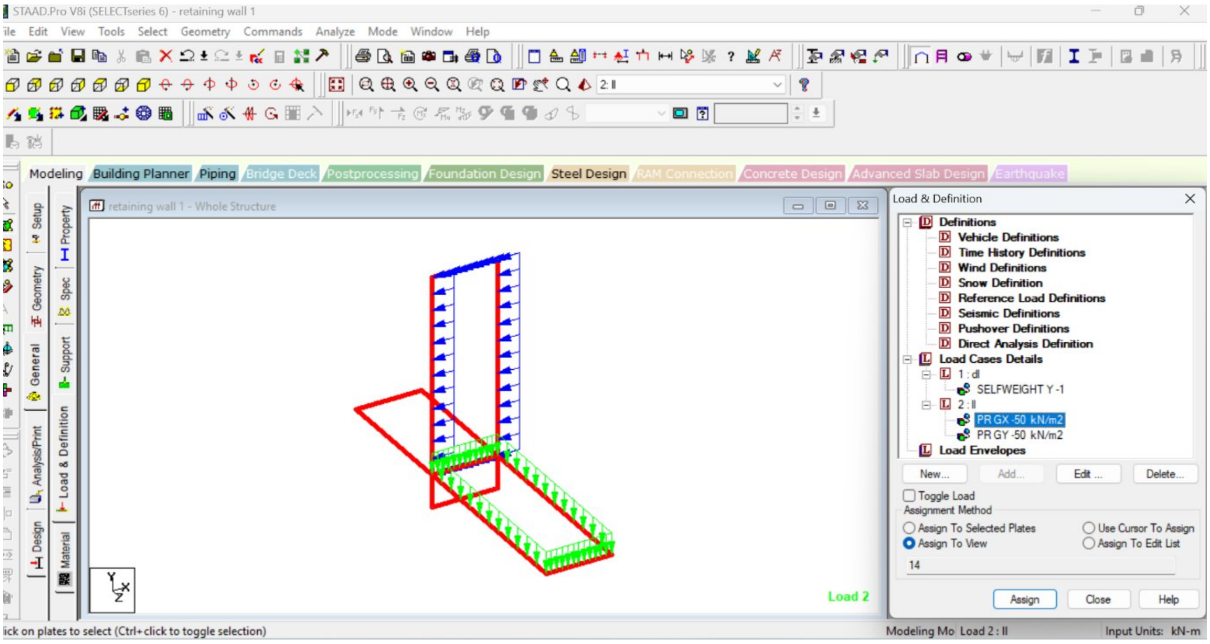


Fig. 8.5: Application of Loads (Self-weight and Earth Pressure)

6. We are **assigning structural material properties** to the modelled plate elements to transform the geometric design into a functional, simulation-ready retaining wall.

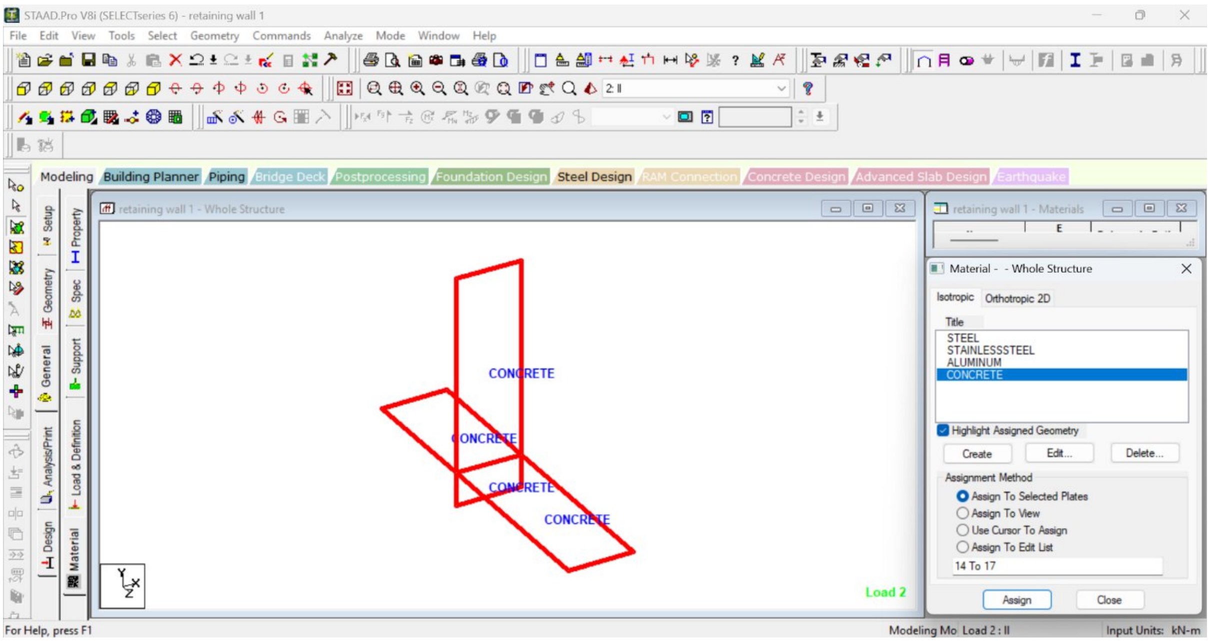


Fig. 8.6: Assignment of Material Properties to Elements

7. In this image, we are **executing the computational core** by configuring the final analysis commands to solve the structure's equilibrium and verify its stability against applied loads

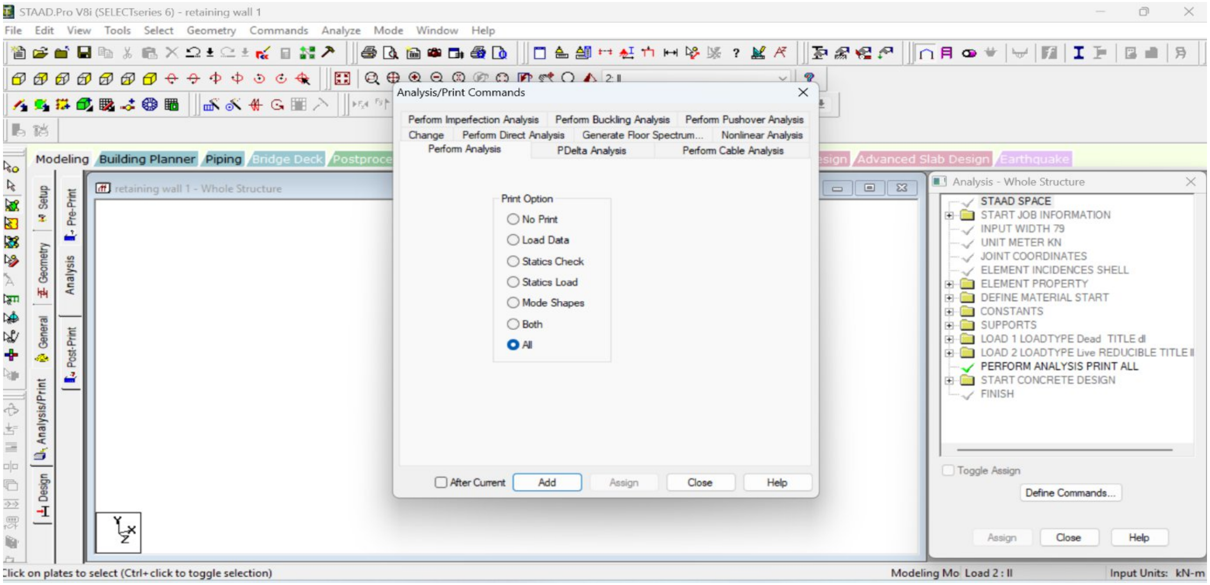


Fig. 8.7: Execution of Structural Analysis

8. That is the "green light" every engineer looks for—**zero errors and zero warnings** mean your model is mathematically sound and the solver successfully reached a solution.

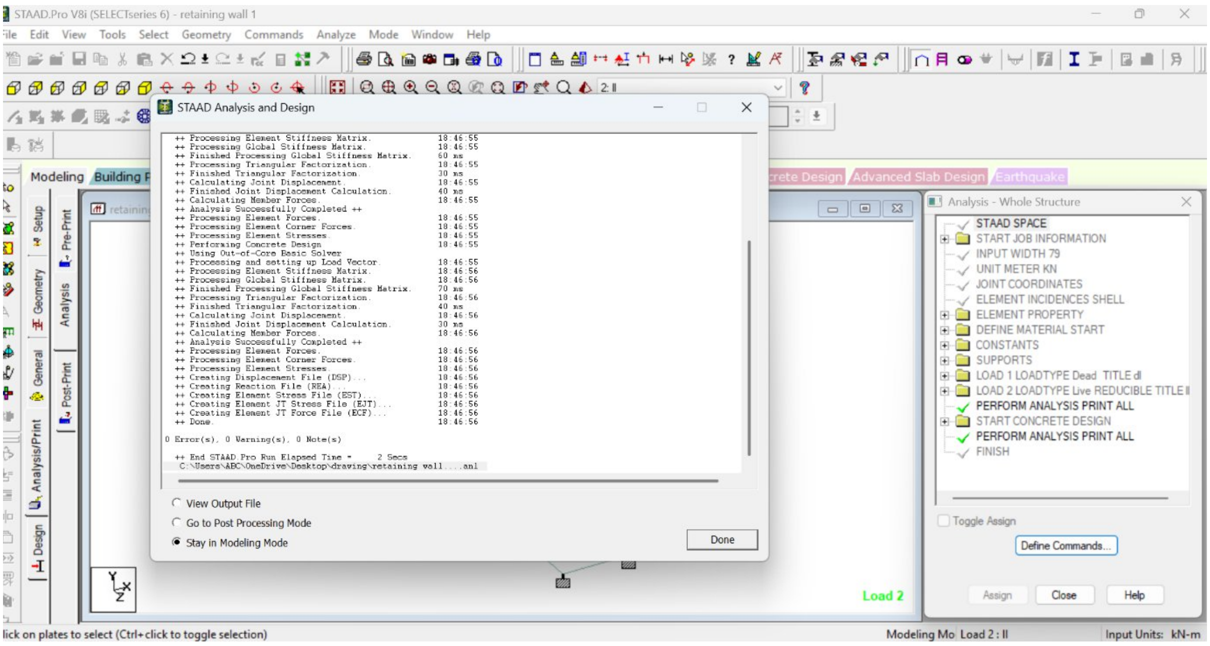


Fig. 8.8: Analysis Output Showing Zero Errors and Warnings

9. In this stage, we are **analysing the structural response** through a displacement contour to verify that the wall's deflection remains within permissible serviceability limits.

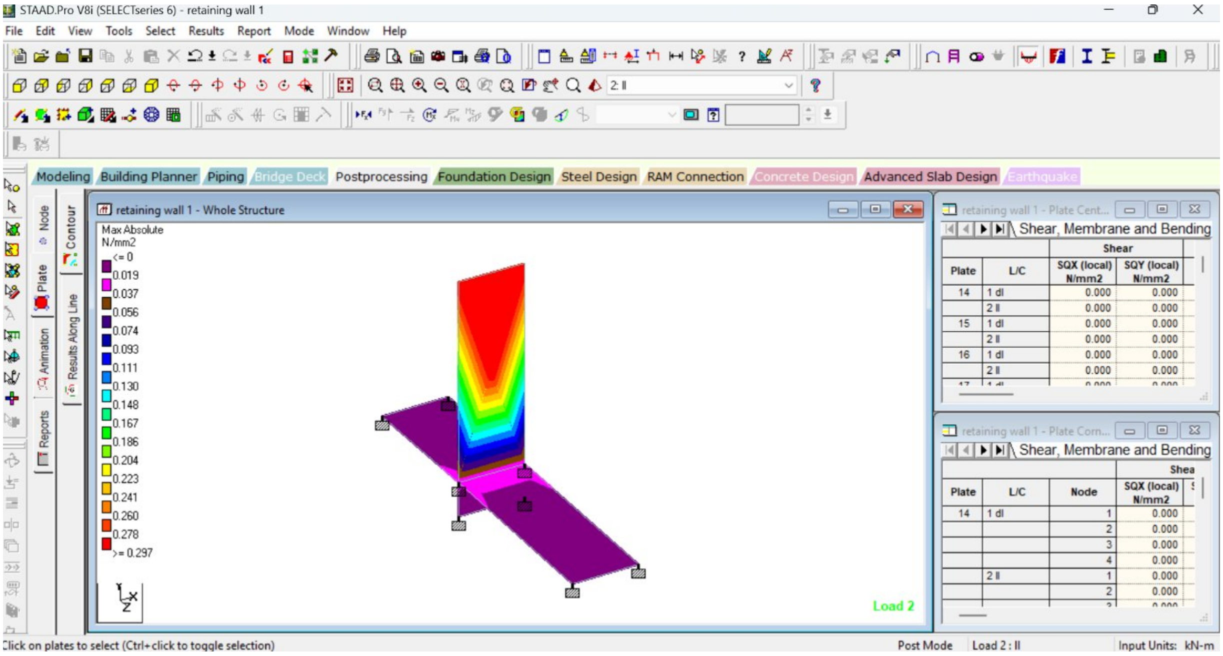


Fig. 8.9: Displacement Contour Showing Deflection Behaviour

10. In this step, we are **extracting the support reactions and equilibrium data** to verify the total base shear and vertical bearing pressure against our global load combinations.

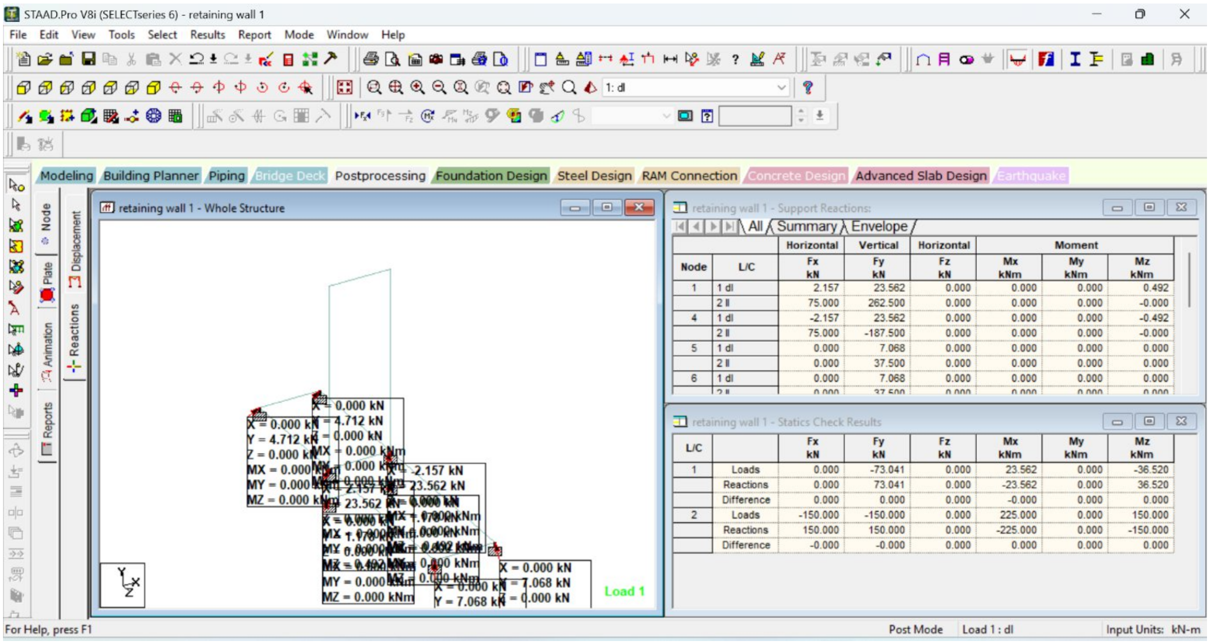


Fig. 8.10: Support Reactions and Base Force Distribution

11. In this view, we are **performing a stress contour analysis** to map the plate force distribution across the retaining wall's surface.

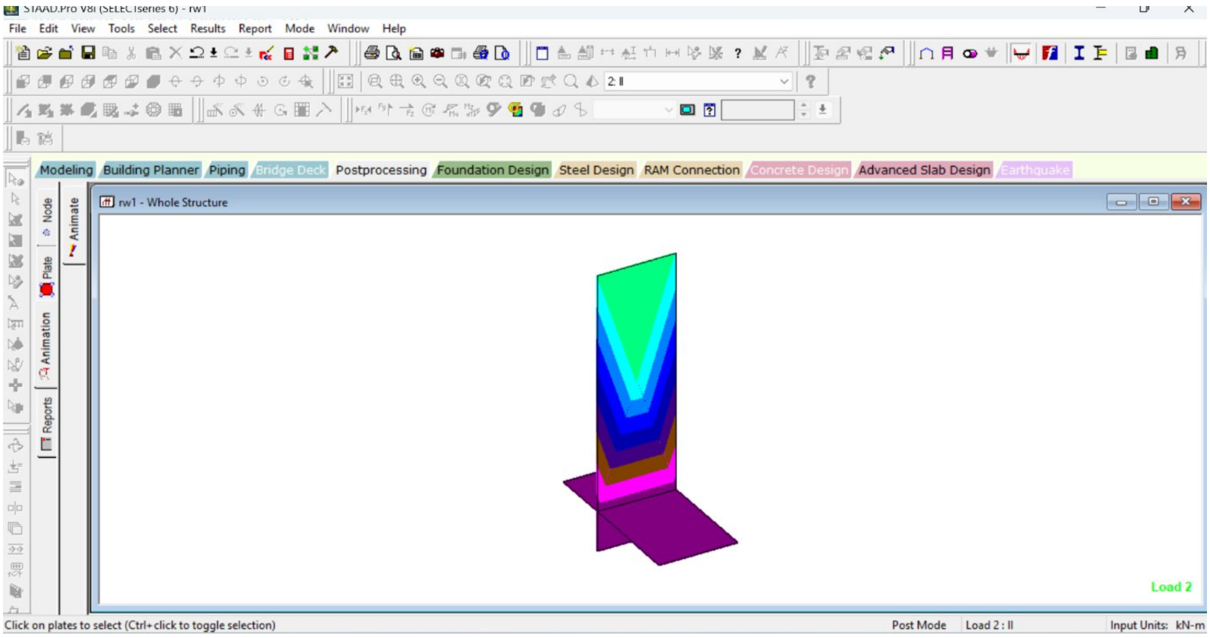


Fig. 8.11: Stress Contour Distribution in Retaining Wall

9 CONCLUSION

The **cantilever retaining wall** has been designed and analysed with a focus on **stability, safety, and efficiency**. Retaining walls are essential for **supporting soil masses**, **preventing erosion**, and **protecting adjacent structures**. This study ensures the wall can safely resist all anticipated loads, including **self-weight**, **lateral earth pressure**, and **surcharge**.

By carefully selecting the **stem, base, and heel dimensions**, the design achieves **resistance against overturning, sliding, and excessive bearing pressure**. Consideration of **soil properties**, **coefficient of friction**, and **safe bearing capacity** ensures compliance with **engineering standards**. **Factor of safety calculations** confirm the wall's reliability under both static and dynamic conditions, while material usage is optimized for **cost-effectiveness**.

The project highlights the practical application of **theoretical principles** in real-world engineering. It emphasizes the importance of **site-specific evaluation**, as soil characteristics and loading conditions can affect performance. Regular **inspection and maintenance** are recommended to monitor for **cracks, water seepage, or soil erosion**, ensuring **long-term durability**.

In summary, the designed retaining wall is **structurally sound, safe, and efficient**, providing a reliable solution for **soil retention**. This project demonstrates the integration of **theory and practice**, emphasizing **safety, functionality, and sustainability** in civil engineering design.

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