COST OPTIMIZATION OF CANTILEVER RETAINING WALL

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Project Report Submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

in

Civil Engineering

by

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CERTIFICATE

This is to certify that the project entitled *Cost Optimization of Cantilever Retaining Wall* submitted by Mr. *Abhinab Jena* (Roll No. 10601009) and Mr. *V. Aravinda Ramanujam* (Roll. No. 10601013) in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at NIT Rourkela is an authentic work carried out by them under my supervision and guidance.

Date: 13-5-2010

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ACKNOWLEDGEMENT

We would like to thank NIT Rourkela for giving us the opportunity to use their resources and work in such a challenging environment.

First and foremost we take this opportunity to express our deepest sense of gratitude to our guide *Prof. S.K. Das* for his able guidance during our project work. This project would not have been possible without his help and the valuable time that he has given us amidst his busy schedule.

We would also like to extend our gratitude to *Prof. M. Panda, Head, Department of Civil Engineering* who has always encouraged and supported in doing our work.

Besides, we are grateful to *Prof. B. Manna* for his valuable guidance through the project. Moreover, we take this opportunity to thank all our friends who have been instrumental in making this project a success.

Last but not the least we would like to thank all the staff members of Department of Civil Engineering who have been very cooperative with us.

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Abstract:

This thesis presents a lucid model to obtain the optimum cost of a cantilever retaining wall having different cases of backfill (straight and inclined) and surcharge. A code written in Java, finds out all the sections of the cantilever retaining wall possible according to stability criteria that applies to all retaining walls and gives the optimum cost of a retaining wall of a given height and the required material properties to be used, while following the provisions of the Indian Standard Code, IS 456:2000for the sections. The freedom given for the person who uses the program to specify material properties and their costs add to the versatility of the code.

Chapter 1

1.1. Introduction:

Retaining walls are structures that are used to retain earth (or any other material) in a position where the ground level changes abruptly. They can be of many types such as gravity wall, cantilever wall, counterfort wall and buttress wall among others. The ‘cantilever wall’ is the most common type of retaining wall and is economical heights up to about 8 m. The lateral force due to earth pressure is the main force that acts on the retaining wall which has the tendency to bend, slide and overturn it [1].

The present thesis focuses on designing the cantilever type of wall giving the most economic section. The main considerations are the external stability of the section and the adherence to the recommendations of IS 456:2000. Satisfying the external stability criteria is primarily based on the section giving the required factor of safety. The ratio of resisting forces to the disturbing forces is the factor of safety, and this factor of safety should always be greater than unity for the structure to be safe against failure with respect to that particular criteria. Different modes of failure have different factors of safety.

In this thesis the most economic section for a cantilever wall is obtained using a computer program that calculates various sections satisfying the stability criteria, according to the height and properties of earth that the wall is required to support, and gives the most economical section as the output after minimizing the cost for sections adhering to provisions of IS 456:2000.

Chapter 2

2.1 Cantilever Retaining Wall:

The cantilever wall generally consists of a vertical stem, and a base slab, made up of two distinct regions, viz. a heel slab and a toe slab. All three components behave like one-way cantilever slabs: the 'stem' acts as a vertical cantilever under the lateral earth pressure; the 'heel slab' and the 'toe slab' acts as a horizontal cantilever under the action of the resulting soil pressure. The reinforcement detailing is as given in Fig. 2.1. The weight of the earth retained helps in maintaining the stability of the wall [2].

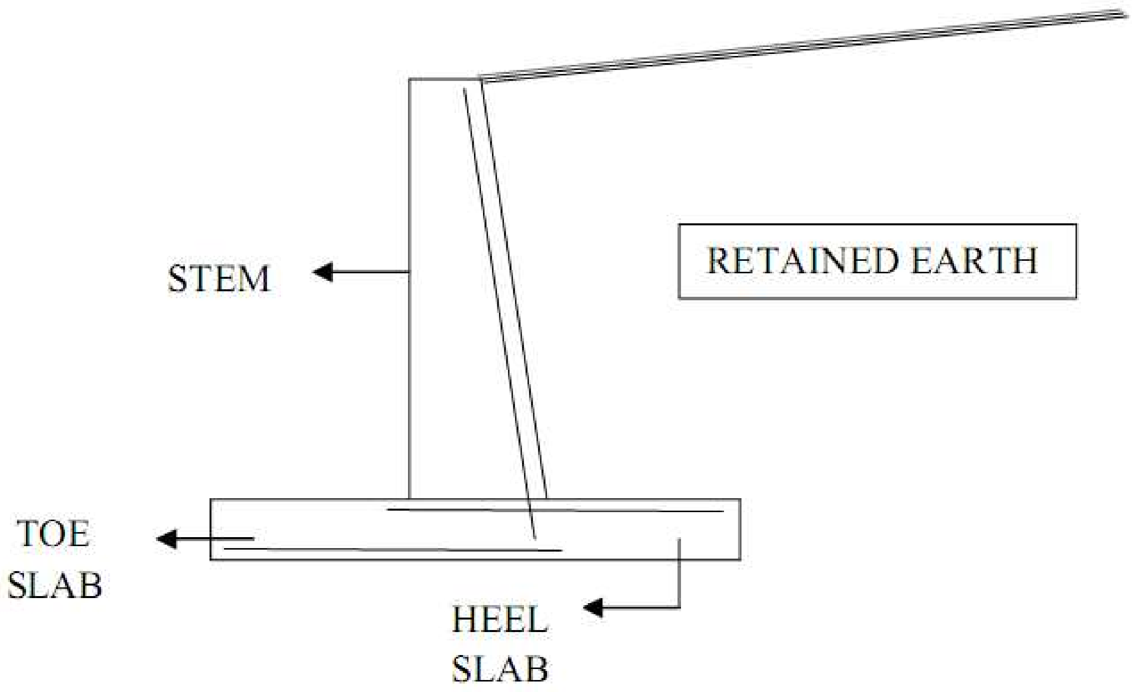

Fig. 2.1 Cantilever Retaining Wall

2.2 Lateral Earth Pressure on Retaining wall:

The main force acting on the retaining wall is constituted by lateral earth pressure which tends to bend, slide and overturn it. The basis for determining the magnitude and direction of the earth pressure are the principles of soil mechanics. The behavior of lateral earth pressure is similar to that of a fluid, with its magnitude pressure increasing nearly linearly with increasing depth *z* for moderate depths below the surface. [3]:

$$p = K\gamma_e z \tag{2.1}$$

Where γ_e is the unit weight of the earth and *K* is a coefficient that depends on its physical properties, and on whether the pressure is active or passive. The coefficient to be used in Eq. 2.1 is the active pressure coefficient K_a, in case of active pressure, and the passive pressure coefficient K_p, in case of passive pressure, Rankine's theory is applied for cohesion less soils and level backfills and the following expressions for K_a and K_p may be used [4]:

$$K_a = \frac{1 - sin\varphi}{1 + \sin\varphi} \qquad \text{(2.2 a)}$$

$$K_p = \frac{1 + sin\varphi}{1 - \sin\varphi} \qquad \text{(2.2 b)}$$

Where φ is the angle of shearing resistance.

When the backfill is sloped, the expression for K_a should be modified as follows:

$$K_a = \left[\frac{cos\varphi - \sqrt{(cos^2\theta - cos^2\varphi}}{cos\varphi + \sqrt{(cos^2\theta + cos^2\varphi}}\right] cos\,\varphi \tag{2.3}$$

Where φ is the angle of inclination of the backfill, i.e., the angle of its surface with respect to the horizontal [3].

2.3 Stability of a cantilever retaining wall [3]:

Fig. 2.2 shows a cantilever retaining wall subjected to the following forces:

1. Weight W_1 of the stem AB.
2. Weight W_2 of the base slab DC
3. Weight W_3 of the column of soil supported on the heel slab BC
4. Horizontal force Pa, equal to active earth pressure acting at H/3 above the base.

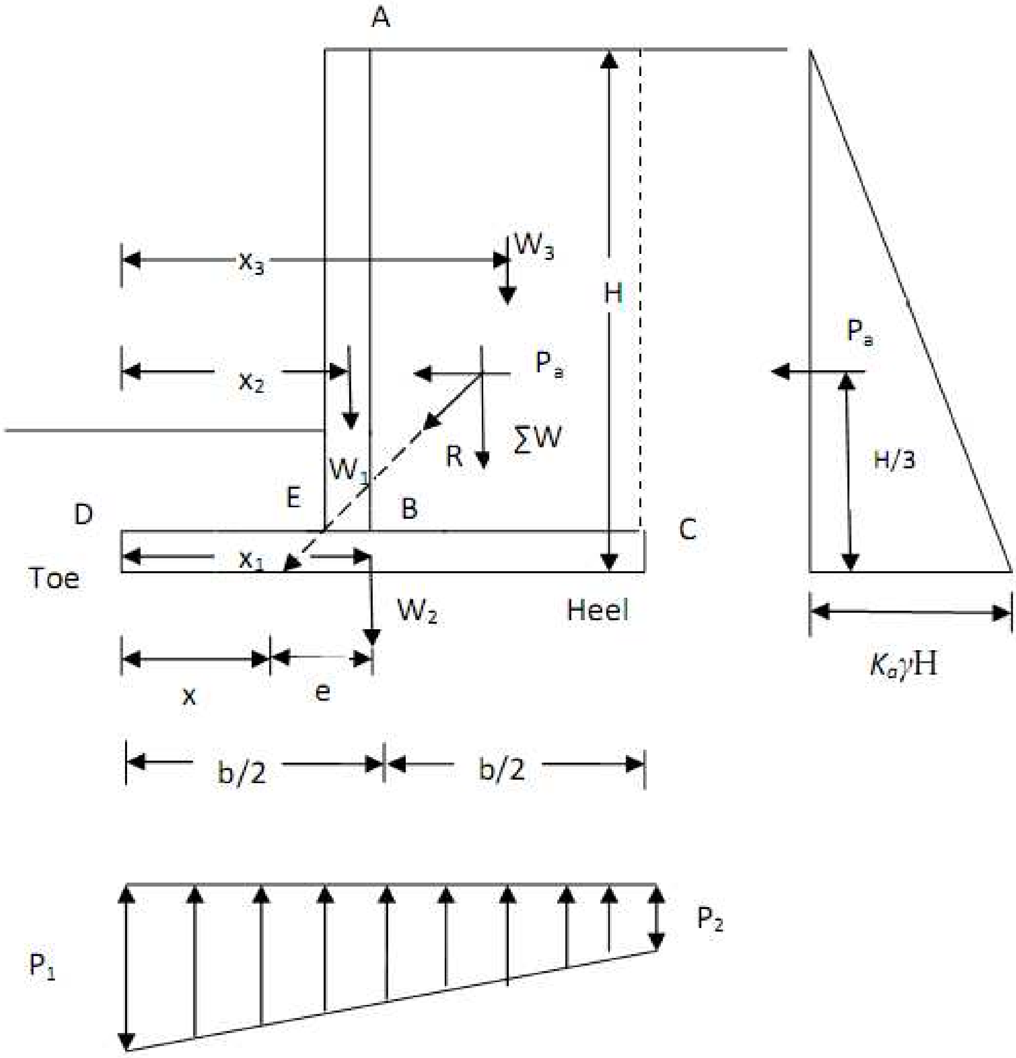

Fig. 2.2 Schematic Representation of Forces Acting On a Cantilever Retaining Wall

2.4 Analysis of the Cantilever Retaining Wall

1. **Overturning:**

In Fig. 2.2, the overturning moment, due to active earth pressure, at toe is

$$M_0 = P_a\, H/3 = K_a\, \gamma H^2/2.\ H/3 \qquad (2.4)$$
$$= K_a\, \gamma H^3/6$$

The resisting moment is due to the weights W_1, W_2 and W_3, neglecting the passive earth pressure and weight of soil above the toe slab.

Hence, $$M_R = W_1\, x_1 + W_2\, x_2 + W_3\, x_3 \qquad (2.5)$$

Hence the factor of safety due to overturning (F_1) is given by

$$F_1 = \frac{M_R}{M_0} \qquad (2.6)$$

A minimum factor of safety due to 2 is adopted.

2. **Sliding [5]:**

The horizontal force P_a tends to slide the wall away from the fill. The tendency to resist this is achieved by the friction at the base (Fig. 2.3(b)).

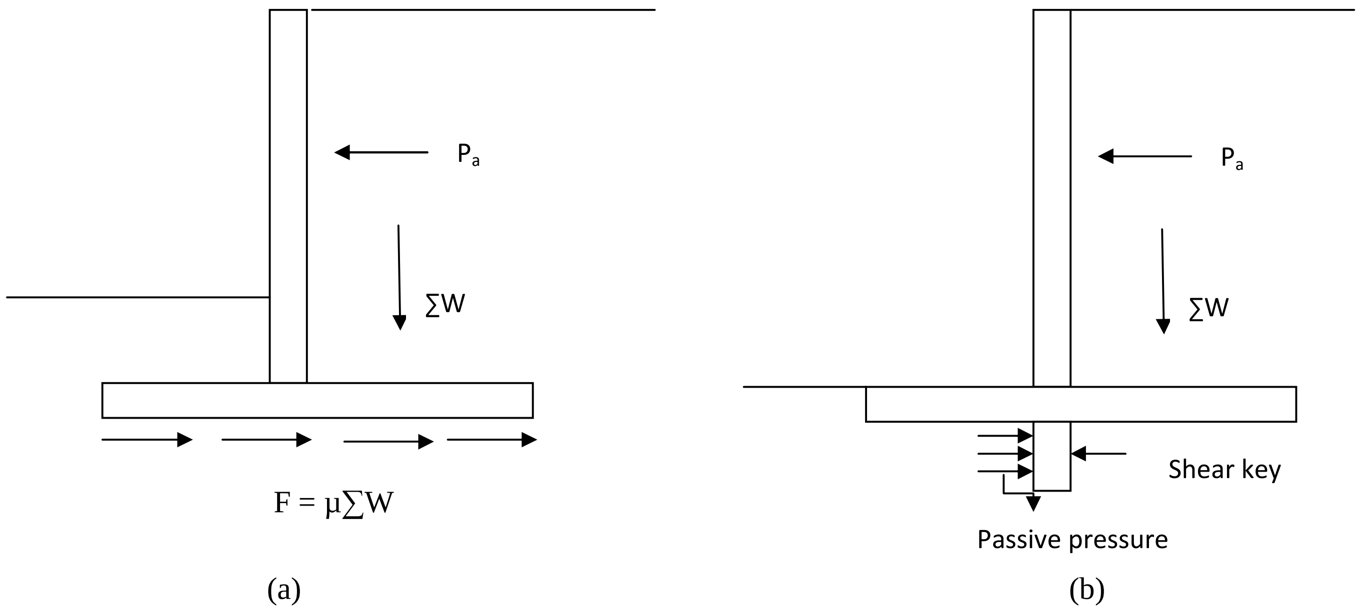

Fig.2.3 Sliding Of Retaining Wall

The force of resistance, F is given by

$$F = \mu\sum W \qquad (2.7)$$

Where μ is the coefficient of friction between soil and concrete, and $\sum W$ is the sum of vertical forces.

The factor of safety F_2 due to sliding is given by

$$F_2 = \frac{\mu\sum W}{H} \qquad (2.8)$$

Where $H = P_a$.

If the wall is found to be unsafe against sliding, shear key below the base is provided. Such a key develops passive pressure which resists completely the sliding tendency of the wall. A factor of safety of 1.5 is needed against sliding.

3. Soil pressure distribution:

Fig. 2.2 shows the various forces acting on the wall. If $\sum W$ is the sum of all vertical forces and P_a is the horizontal active earth pressure, the resultant R will strike the base slab at a distance *e* (say) from the middle point of the base.

Let $\sum M = W_1 x_1 + W_2 x_2 + W_3 x_3 - P_a . H/3$ = net moment at the toe.

Then x = distance of point of application of resultant = $\frac{\sum M}{\sum W}$

Hence eccentricity $e = b/2 - x$

The pressure distribution below the base is shown in Fig. 2.1. The intensity of soil pressure at the toe and heel is given by

$$p_1 = \frac{\sum W}{b}\left(1 + \frac{6\,e}{b}\right) \text{ at toe} \qquad (2.9)$$

$$p_2 = \frac{\sum W}{b}\left(1 - \frac{6\,e}{b}\right) \text{ at heel} \qquad (2.10)$$

p_1 at toe should not exceed the safe bearing capacity of the soil otherwise soil will fail. Similarly, p_2 at hell should be compressive. If p_2 becomes tensile, the heel will be lifted above the soil, which is not permissible. In an extreme case, p_2 may be zero, where $e = b/6$. Hence in order that tension is not developed, the resultant should strike the base within the middle third.

4. **Bending failure:**

There are three distinct parts of T-shaped cantilever retaining wall: the stem AB, the heel slab BC and the toe slab DE. The stem AB will bend as cantilever, so that tensile face will be towards the backfill. The heel slab will have net pressure acting downwards, and will bend as a cantilever, having tensile face upwards. The pressure distribution will be as shown in Fig. 2.3. The critical section will be at B, where cracks may occur if it is not reinforced properly at the upper face. The net pressure on toe slab will act upwards, and hence it must be reinforced at the bottom face. The thickness of stem, hell slab and toe slab must be sufficient to withstand compressive stresses due to bending.

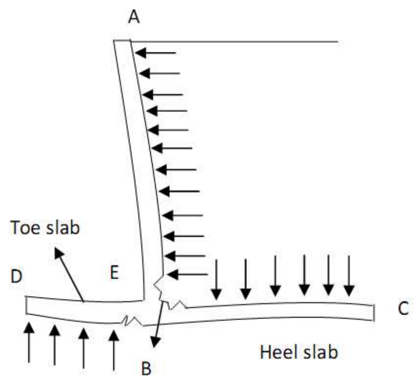

Fig. 2.4Bending failure

2.5 Basic design considerations:

1. **Design of stem:**

   The stem AB is designed as a cantilever, for triangular loading. At any section h below the top point A, the force is equal to $K_a\ \gamma H^2/2$ and its bending moment about the section is $K_a\ \gamma H^3/6$. The thickness at B is maximum. The minimum thickness at A should vary from 20 to 30 cm depending upon the height of the wall. Reinforcement is provided towards the inner face of stem, i.e. towards side of fill. The requirement towards the top of stem can be curtailed, since B.M. varies as h^3. Distribution reinforcement is provided @ 0.15% of the area of cross-section along the length of retaining wall at inner face. Similarly, at the outer face of the stem, temperature reinforcement is provided both in horizontal as well as in vertical direction, at the rate of 0.15% of the area of cross-section.

2. **Design of heel slab:**

   The heel is also to be designed as a cantilever. It has both downward pressure (due to weight of soil and self-weight) as well as upward pressure due to soil reaction. However, the net pressure is found to act downward and hence reinforcement is provided at the upper face BC.

3. **Design of toe slab:**

   Neglecting the weight of the soil above it, the toe slab will bend upwards as a cantilever due to upward soil reaction. Hence reinforcement is placed at the bottom face. Normally, the thickness of both toe slab and heel slab is kept the same, determined on the basis of greater of the cantilever bending moments.

4. **Depth of foundation:**

   As shown in Fig. 2.4, the height H_2 of the retaining wall, above ground level is fixed on the basis of height of the backfill to be retained. The depth of foundation y should be such that good quality of soil to bear the induced pressure is available. However, a minimum depth of foundation given below by Rankine's formula should be provided:

$$y_{min} = \frac{q_0}{\gamma} K_a^2 \quad (2.11)$$

Where q_0 is the safe bearing capacity of the soil, or equal to the maximum pressure likely to occur on soil.

Chapter 3

3.1 Specific codal provisions followed while optimizing [6]:

The program developed in this thesis for economic design of a cantilever retaining wall is guided by certain provisions of the code IS 456:2000, which are given below:

1. **Spacing of reinforcement:**

   For the purpose of this clause, the diameter of a round bar shall be its nominal diameter, and in the case of bars which are not round or in the case of deformed bars or crimped bars, the diameter shall be taken as the diameter of a circle giving an equivalent effective area. Where spacing limitations and minimum concrete cover are based on bar diameter, a group of bars bundled in contact shall be treated as a single bar of diameter derived from the total equivalent area.

1.1 Minimum distance between individual bars:

The following shall apply for spacing of bars:

a) The horizontal distance between two parallel main reinforcing bars shall usually be not less that ha greatest of the following:

1. The diameter of the bar if the diameters are equal,
2. The diameter of the larger bar if the diameters are unequal, and
3. 5 mm more than the nominal maximum size of coarse aggregate.

b) Greater horizontal distance than the minimum specified in (a) should be provided wherever possible. However when needle vibrators are used the horizontal distance between bars of a group may be reduced to two-thirds the nominal maximum size of the coarse aggregate, provided that sufficient space is left between groups of bars to enable the vibrator to be immersed.

c) Where there are two or more rows of bars, the bars shall be vertically in line and the minimum vertical distance between the bars shall be 15mm, two-thirds the nominal maximum size of aggregate or the maximum size of bars, whichever is greater.

2. Nominal cover to reinforcement:

   a) Nominal cover:

      Nominal cover is the design depth of concrete cover to all steel reinforcements, including links. It is the dimension used in design and indicated in the drawings. It shall be not less than the diameter of the bar.

   b) Nominal cover to meet durability requirement:

      Minimum values for the nominal cover of normal-weight aggregate concrete which should be provided to all reinforcement, including links depending on the condition of exposure.

   c) For footings minimum cover shall be 50mm.

3. Requirements of reinforcement for structural members:

   a) Beams

      a.1) Tension reinforcement:

      i) Minimum reinforcement

      The minimum area of tension reinforcement shall be not less than that given by the following:

$$\frac{A_s}{bd} = \frac{0.85}{f_y} \qquad (3.8)$$

Where A_s = minimum area of tension reinforcement

b = breadth of beam or the breadth of the web of T-beam

d = effective depth

f_y = characteristic strength of reinforcement in N/mm^2

      ii) Maximum reinforcement – The maximum area of tensile reinforcement shall not exceed 0.04 bD.

   b) Maximum spacing of shear reinforcement:

      The maximum spacing of shear reinforcement measured along the axis of the member shall not exceed 0.75 *d* for vertical stirrups and *d* for inclined stirrups at

45˚, where d is the effective depth of the section under consideration. In no case shall the spacing exceed 300 mm.

4. Minimum shear reinforcement:

   Minimum shear reinforcement in the form of stirrups shall be provided such that:

$$\frac{A_{sv}}{bs_v} \geq \frac{0.4}{0.87\, f_y} \qquad (3.9)$$

Where A_{sv}= total cross-sectional area of stirrup legs effective in shear,

s_v= stirrups spacing along the length of the member,

b = breadth of the beam or breadth of the web of flanged beam, and

f_y= characteristic strength of the stirrup reinforcement in N/mm^2 which shall not be taken greater than 415 N/mm^2.

Chapter 4

4.1 Problem overview:

In this project, as we have aimed to obtain the cantilever retaining wall section costing minimum for the three cases of backfill and related input parameters, that we have considered, namely:

1. Horizontal backfill with static surcharge
2. Inclined backfill, with shear key and without surcharge load
3. Inclined backfill with surcharge load
4. Inclined backfill without surcharge load and provision to vary cost of construction by using different grades of concrete
5. Inclined backfill without traffic load and provision to vary cost of construction by using different grades of steel
6. Inclined backfill without traffic load and provision to vary cost of construction by using different grades of concrete and steel.
7. Inclined backfill with surcharge load and to vary the cost of construction by varying the grades of concrete and steel and the prices for each item varies.

4.2 Detailed discussion of the problem:

Now, let us look at each of the above cases in a detailed manner:

1. Horizontal backfill with uniform surcharge:

   If the backfill is horizontal with static surcharge, of uniform intensity *w* per unit area, the vertical pressure increment at any depth *h* increases by *w*.This leads to an increase in lateral pressure by $K_a w$. Therefore, the lateral pressure at any depth *h* will be given by

$$p_a = K_a.\gamma.h + K_a.\ w \qquad (4.1)$$

   this implies that the pressure at the base of the wall is given by

$$p_a = K_a.\gamma.H + K_a.\ w \qquad (4.2)$$

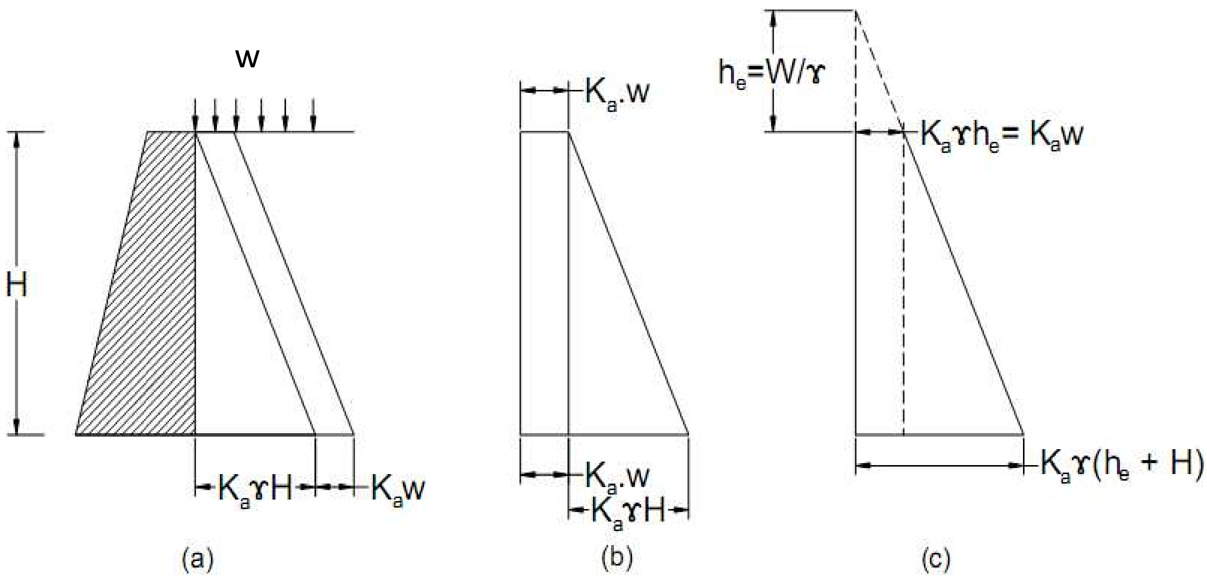

Fig.4.1. Backfill with uniform surcharge

   Fig 4.1(a) and (b) show two alternative methods of plotting the lateral pressure diagram for this case. The increase in lateral pressure due to surcharge is the same at every point of the back of the wall, and it is invariant with *h*.

The equivalent height of the fill h_e is given by:

$$K_a.\gamma.h_e = K_a.w$$

$$\text{or } h_e = \frac{w}{\gamma} \qquad (4.3)$$

which means that the effect of surcharge is the same as that of earth retained to a height of h_e above the ground.

2. Inclined backfill with shear key and without surcharge load:

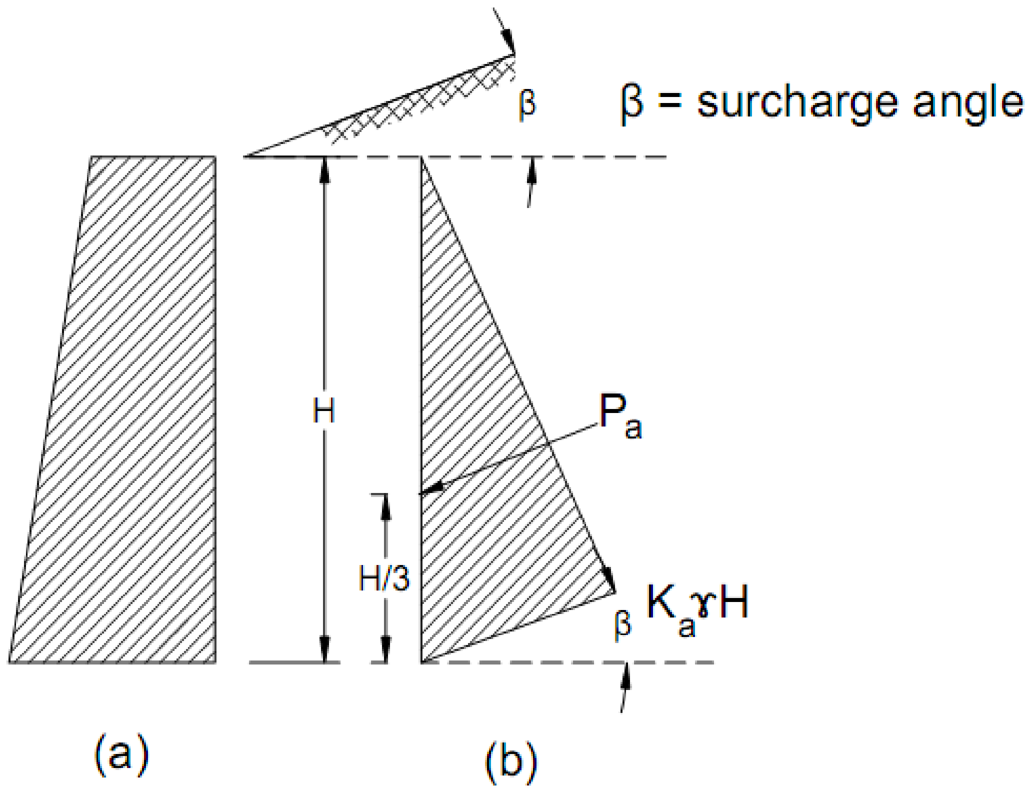

Fig.4.2. Lateral Pressure Distribution for Sloping Surcharge

Let the backfill be inclined at an angle β to the horizontal as shown in Fig. 4.2; β is called the angle of surcharge. An assumption that vertical and lateral stresses are conjugate is made while calculating the active earth pressure for this case by Rankine's theory. Fig. 4.2 shows the retaining wall with a sloping backfill. The intensity of lateral earth pressure at the base of wall is given by:

$$p_a = \gamma H.\left[\frac{cos\beta-\sqrt{(cos^2\beta-cos^2\varphi)}}{cos\beta+\sqrt{(cos^2\beta+cos^2\varphi)}}\right]cos\,\beta$$

$$\text{or}\,p_a = K_a\gamma H \tag{4.4}$$

$$\text{where } K_a = \left[\frac{cos\beta-\sqrt{(cos^2\beta-cos^2\varphi)}}{cos\beta+\sqrt{(cos^2\beta+cos^2\varphi)}}\right]cos\,\beta.$$

The pressure acts parallel to the sloping surface, i.e., at β with the horizontal. The total active pressure P_a for the wall of height H is given by

$$P_a = \frac{1}{2} K_a \gamma H^2 \qquad (4.5)$$

The resultant acts at H/3 above the base, in direction parallel to the surcharge.

Provision of shear key:

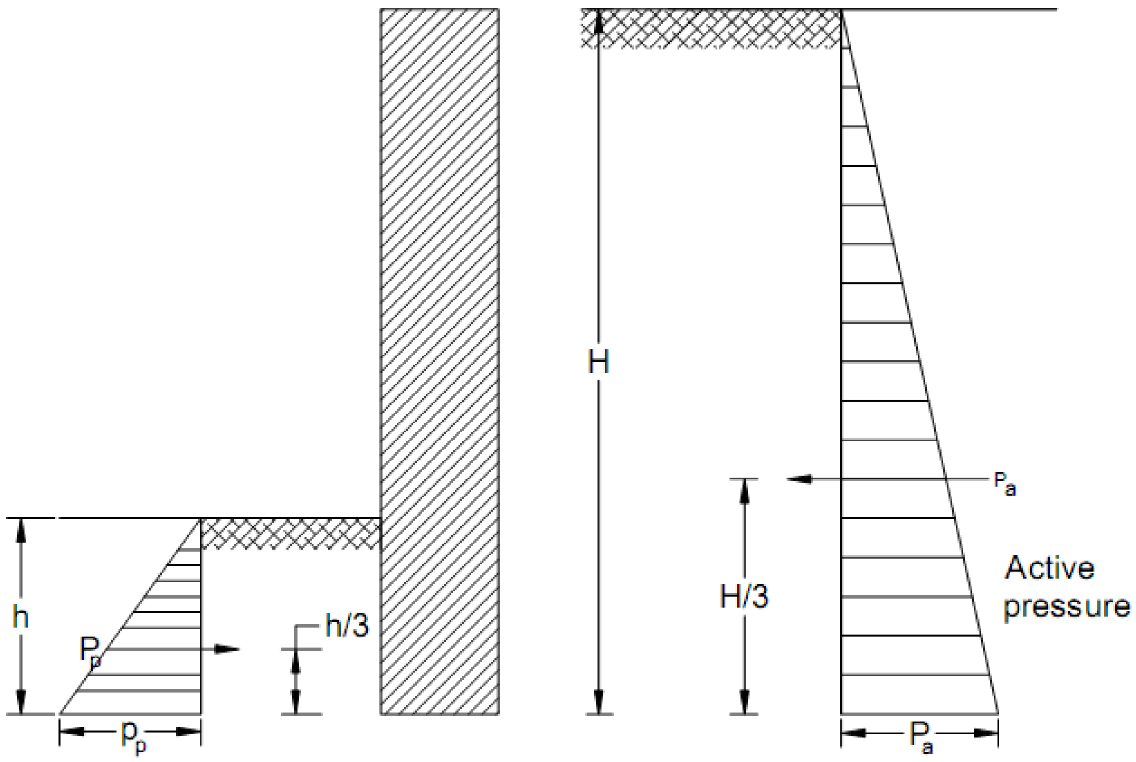

Fig.4.3. Passive Earth Pressure Distribution for Shear Key

When the reinforcing wall fails against sliding, then an arrangement called shear key is provided. As the retaining wall pushes against the soil at the zone where shear key, as shown in Fig. 4.3 is provided, the shear key has to be designed for passive earth pressure. This can be explained by the fact that due to active earth pressure from the right side, the wall moves to the left. The soil to the left is thus compressed and in turn exerts passive earth pressure, resisting that movement.

If h is the height of fill, the intensity of passive pressure at height h is given by

$$p_p = K_p.\gamma h \tag{4.6}$$

Where K_p is the coefficient of passive earth pressure and

$$K_p = \frac{1+sin\varphi}{1-sin\varphi} = \frac{1}{K_a}$$

The passive pressure distribution will thus be a triangle, much like the one for active pressure distribution. The total pressure is given by

$$P_p = K_p.\frac{\gamma h^2}{2} \tag{4.7}$$

acting at $h/3$ above base.

3. **Inclined backfill with surcharge load[7]:**

   This case is as given in Fig. 4.4 and may be treated as a combination of the first two cases wherein the part for surcharge load is done as Case 1 and the shear key part is done as Case 2.

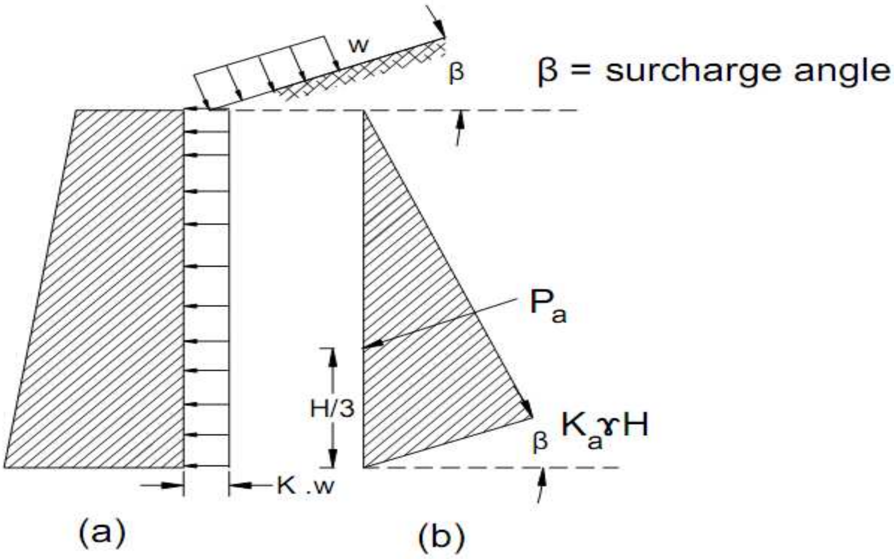

Fig.4.4. Lateral Pressure Distribution on Inclined Backfill with Surcharge

4. **Surcharge load and provision to change grade of concrete:**

   This case incorporates freedom in specifying the different grades of concrete in the case considered in Case 2.

5. **Surcharge load and provision to change grade of steel**

   This case incorporates freedom in specifying the different grades of steel in the case considered in Case 2.

6. **Surcharge load and provision to change grade of concrete and steel:**

   This case incorporates the variation of the grades of both concrete and steel in the case considered in Case 2.

7. **Surcharge load with the provision to change grade of concrete and steel and their costs.**

   The program calculates the minimum cost by using different grades of concrete and steel and pricing for the each grade of concrete and steel are different and can be changed as the requirement of the user, rest of the details being the same as in Case 3.

Chapter 5

5.1 Model formulation:

The basic purpose of the model developed here is to obtain the minimum cost of a cantilever retaining wall supporting backfill of a particular height. It is kept in mind that when the grade of the concrete becomes higher, then, the section dimensions are reduced while the cost of construction goes up significantly. So, the model is specifically formulated to give freedom to specify the different costs of construction for different grades of concrete and steel separately and in a combined way at a later stage of the program. The model is formulated in two major steps: (1) finalizing the design variables to be given importance; (2) the technique that is to be adopted to find the minimum cost of the wall [8].

5.2 Programming to get minimum cost:

The central idea in building the program is to provide a number of parameters that can be varied at the input level giving the program great flexibility to design the retaining wall according to various considerations like cost, aesthetics, varying site conditions, availability of materials and workmanship, requirements of the client, etc. The decision variables on the basis of which the cost optimization is done are grade of concrete (f_{ck}) and grade of steel (f_y). The function that the program performs is to reduce the dimensions of the base slab, stem and the toe slab so that we may get the section where further reduction of dimensions is not possible.[9][10]

a) Case 1:

In the case of horizontal backfill with traffic load, the input parameters given in the program are

1. Total Height of Retaining wall = H
2. Yield strength of steel = f_y
3. Characteristic compressive strength of concrete = f_{ck}
4. Coefficient of friction between base slab and the ground = μ
5. Traffic load intensity = q
6. Internal friction angle of backfill soil = φ
7. Unit weight of backfill soil = U_1
8. Unit weight of concrete = U_2
9. Unit weight of foundation soil = U_3
10. Permissible shear stress for the concrete = T
11. Internal friction angle of foundation soil = θ

b) Case 2:

The case of inclined surcharge with shear key and without traffic load has the following input parameters:

1. Height of soil to be retained(m) = h
2. Yield strength of steel for main reinforcement (N/mm^2) = f_{y1}
3. Yield strength of steel for distribution reinforcement (N/mm^2) = f_{y2}
4. Characteristic compressive strength of concrete = f_{ck}
5. Angle of backfill = A_1
6. Internal friction angle of backfill soil = A_2
7. Internal friction angle of backfill soil = A_3
8. Unit weight of backfill soil = U_1
9. Unit weight of concrete = U_2
10. Unit weight of foundation soil = U_3
11. Safe bearing capacity of soil = P_b
12. Coefficient of friction between base slab and the ground = f_f
13. Cost of per m^3 of concrete = C_c
14. Cost of per kg of reinforcement = C_s

c) Case 3:

The case of inclined surcharge with shear key and traffic load has the following input parameters:

1. Height of soil to be retained = h
2. Yield strength of steel for main reinforcement = f_{y1}
3. Yield strength of steel for distribution reinforcement = f_{y2}
4. Characteristic compressive strength of concrete = f_{ck}
5. Angle of backfill = A_1
6. Internal friction angle of backfill soil = A_2
7. Internal friction angle of backfill soil = A_3
8. Surcharge load = q
9. Unit weight of backfill soil = U_1
10. Unit weight of concrete = U_2
11. Unit weight of foundation soil = U_3
12. Safe bearing capacity of soil = P_b
13. Coefficient of friction between base slab and the ground = f_f
14. Cost of per m^3 of concrete = C_c
15. Cost of per kg of reinforcement = C_s

d) Case 4:

A modification is introduced in program for Case 2 to compute the minimum cost of retaining wall for different grades of concrete and Fe 250 steel. So in addition to the parameters of Case 2, grade of concrete is also included in the input list.

e) Case 5:

A modification is introduced in program for Case 2 to compute the minimum cost of retaining wall for different grades of steel and M 25 concrete. In addition to the input parameters given under Case 2, the grade of steel is also brought under input parameter list.

f) Case 6:

A modification is introduced in program for Case 2 to compute the minimum cost of retaining wall for different grades of concrete and steel. In addition to the input parameters given under Case 2, grade of both concrete and steel is also brought under input parameter list.

g) Case 7:

In Case 7, the minimum cost of the cantilever retaining wall is calculated for different grades of concrete and steel having different costs of construction, and the rest of the input parameters being same as in Case 3.

Chapter 6

6.1 Results and Discussion:

The results and the discussions of the Cases 1 to 7 have been presented here.

Case 1:

Input:

Height of backfill	= 4 m
Yield strength of steel	= 250 N/mm^2
Concrete compressive strength	= 25 N/mm^2
Internal friction angle of backfill soil	= 30°
Surcharge load	= 16 kN/m^2
Unit wt. of backfill soil	= 18 kN/m^3
Unit wt. of concrete	= 25 kN/m^3
Allowable bearing pressure	= 160 kN/m^2
Internal friction angle of foundation soil	= 25°
Unit wt. of foundation soil	= 16 kN/m^3
Cost per cubic meter of concrete	= INR 3237
Cost per kilogram of steel	= INR 42

Output:

Minimum Cost	= INR 15221.10
Optimum Width of base	= 2.50 m
Optimum thickness of base	= 0.2 m
Optimum thickness of stem at bottom	= 0.43 m
Factor of safety provided against overturning	= 2.2
Factor of safety provided against sliding	= 2.06
Maximum Pressure under the Base	= 51.40kN/m^2
Optimum Steel in toe	= 1114.55
Optimum Steel in heel	= 1274.75
Optimum Steel at stem	= 4297.86

Discussion:

The program takes up the design of the retaining wall with horizontal backfill and surcharge load. The output gives the dimension of the most economical section that satisfies the checks and the minimum cost.

Case 2:

Input:

Yield strength of steel	= 250 N/mm^2
Concrete compressive strength	= 30 N/mm^2
Angle of backfill	= 18°
Internal friction angle of backfill soil	= 30°
Unit wt. of backfill soil	= 18 kN/m^3
Unit wt. of concrete	= 25 kN/m^3
Allowable bearing pressure	= 160 kN/m^2
Internal friction angle of foundation soil	= 25°
Unit wt. of foundation soil	= 16 kN/m^3
Cost per cubic meter of concrete	= INR 3237
Cost per kg.of steel	= INR 42

Output:

Table 6.1 - Results of Case 2:-for Height of Backfill 4m and 4.5m

Ht. of Earth retained(m)	4	4.5
Minimum Cost(INR)	26143.51	32020.85
Optimum Width of base(m)	3.20	3.56
Optimum thickness of base(m)	0.38	0.43
Optimum thickness of stem at bottom(m)	0.25	0.27
Factor of safety provided against overturning	2.36	2.48
Factor of safety provided against sliding	1.57	1.57
Optimum Steel in toe (mm^2)	1921.43	2185
Optimum Steel in heel (mm^2)	2665.64	2997.46
Optimum Steel at stem (mm^2)	8491.41	9613.52

Table 6.2 - Results of Case 2:-for Height of Backfill 5m and 6m

Ht. of Earth retained(m)	5.0	6.0
Minimum Cost(INR)	38758.45	54744.27
Optimum Width of base(m)	4.05	5.01
Optimum thickness of base(m)	0.48	0.57
Optimum thickness of stem at bottom(m)	0.29	0.35
Factor of safety provided against overturning	2.64	2.95
Factor of safety provided against sliding	1.59	1.61
Optimum Steel in toe (mm^2)	2479.22	3124.61
Optimum Steel in heel (mm^2)	3334.47	4027.51
Optimum Steel at stem (mm^2)	10778.5	13226.50

Discussion:-

The results have been computed by changing the height of the soil that has to be retained and the rest of the input parameters were assigned fixed values. The program was executed by changing only the height of the soil that has to be retained; the concrete and steel properties as well as the soil properties remain same. As per the soil height that has to be supported by the wall the depth of foundation is first calculated and subsequently the factor of safety for overturning and sliding are checked.

The results were computed for the different height of soil retained. The output gave the minimum cost of construction that will incur and the dimension of the section that will satisfy all the checks. Thus different dimensions of the stem and base slab effects the cost of concrete and the change in dimension also changing the reinforcement requirement of the section. This in turn changes the cost. The program after checking for the sections computes the cost and then shows the output as the section where the cost is minimum.

The results also give us an idea about how the cost is varying with the change in height of the soil that has to be retained. As the height of soil increases the section also changes and also the reinforcement that has to be provided in the toe, heel and stem. The result shows the minimum cost for various data of the soil height along with it's the dimensions.

Case 3:

Input-

Yield strength of concrete	= 415 N/mm^2
Compressive strength of concrete	= 20 N/mm^2
Coefficient of friction	= 0.6
Angle of backfill	= 15°
Internal friction angle of backfill soil	= 28°
Internal friction angle of foundation soil	= 28°
Surcharge load	= 16 kN/m^2
Unit wt. of backfill soil	= 18 kN/m^3
Unit wt. of concrete	= 24 kN/m^3
Unit wt. of foundation soil	= 18 kN/m^3
Allowable bearing pressure	= 160 kN/m^2
Cost per cum of concrete	= INR 3300
Cost per kg of steel	= INR 40

Output: Table 6.3 - Results of Case 3:-for Height of Backfill 4m and 4.5m

Ht. of Earth retainer (m)	4	4.5
Minimum Cost(INR)	16858.50	20141.35
Optimum Width of base (m)	3.70	4.03
Optimum thickness of base (m)	0.40	0.4
Optimum thickness of stem at bottom (m)	0.41	0.46
Factor of safety provided against overturning	3.03	3.04
Factor of safety provided against sliding	1.50	1.5
Optimum Steel in toe (mm^2)	1353.71	1718.44
Optimum Steel in heel (mm^2)	1730.70	2173.39
Optimum Steel at stem (mm^2)	3162.83	3609.38

Table 6.4 - Results of Case 3:-for Height of Backfill 5m and 6m

Ht. of Earth retainer (m)	5.0	6.0
Minimum Cost(INR)	23855.3	32605.53
Optimum Width of base (m)	4.35	5.00
Optimum thickness of base (m)	0.40	0.44
Optimum thickness of stem at bottom (m)	0.51	0.60
Factor of safety provided against overturning	3.10	3.08
Factor of safety provided against sliding	1.50	1.51
Optimum Steel in toe (mm^2)	2140.92	2800.86
Optimum Steel in heel (mm^2)	2680.46	3450.47
Optimum Steel at stem (mm^2)	4073.82	5010.36

Discussion:-

The program analyses the retaining wall supporting an inclined backfill along with surcharge load. The output gives the minimum cost that will be incurred and the dimensions of the sections corresponding to this cost of construction. These sections satisfy all the checks needed for the stability of retaining wall. The results that have been tabulated are obtained just by changing the height of the soil to be retained with rest of the input parameters being constant for every execution. This gives a comparison of the cost and the section that has to be used.

Case 4:

Input:

Coefficient of friction	= 0.6
Yield strength of steel	= 250 N/mm^2
Angle of Backfill	= 18°
Internal Friction angle of backfill soil	= 30°
Unit Weight of Backfill soil	= 18.0 kN/m^3
Unit weight of concrete	= 25.0 kN/m^3
Allowable bearing Pressure	= 160.0 kN/m^2
Internal Angle of foundation soil	= 25°
Unit Weight of foundation soil	= 16.0 kN/m^3
Cost of concrete/cubic meter	= INR 3237.0
Cost of reinforcement per kg	= INR 42.0

Output:

Table 6.5 - Results of Case 4:-for Height of Backfill 4m for different grades of concrete

Grade of concrete	M 20	M 25	M 30	M 35	M 40
Minimum Cost(INR)	23542.79	24908.38	26143.51	27287.83	28361.03
Optimum Width of base (m)	3.17	3.19	3.20	3.21	3.22
Optimum thickness of base (m)	0.37	0.38	0.38	0.39	0.40
Optimum thickness of stem at bottom (m)	0.29	0.27	0.25	0.24	0.23
Factor of safety provided against overturning	2.33	2.35	2.36	2.37	2.38
Factor of safety provided against sliding	1.56	1.56	1.57	1.57	1.57
Optimum Steel in toe (mm^2)	1996.66	1958.12	1921.43	1883.78	1846.54
Optimum Steel in heel (mm^2)	2706.18	2688.48	2665.64	2634.59	2598.52
Optimum Steel at stem (mm^2)	6966.83	7769.24	8491.41	9150.86	9760.35

Table 6.6 - Results of Case 4:-for Height of Backfill 4.5m for different grades of concrete

Grade of concrete	M 20	M 25	M 30	M 35	M 40
Minimum Cost(INR)	28755.25	30462.11	32020.85	33465.39	34801.88
Optimum Width of base (m)	3.53	3.57	3.60	3.62	3.64
Optimum thickness of base (m)	0.41	0.42	0.43	0.44	0.45
Optimum thickness of stem at bottom (m)	0.32	0.29	0.27	0.26	0.25
Factor of safety provided against overturning	2.41	2.45	2.48	2.50	2.52
Factor of safety provided against sliding	1.57	1.57	1.60	1.58	1.58
Optimum Steel in toe (mm^2)	2266.70	2221.57	2185.00	2146.87	2106.85
Optimum Steel in heel (mm^2)	3050.84	3024.17	2997.46	2961.15	2920.65
Optimum Steel at stem (mm^2)	7890.64	8796.64	9613.52	10359.28	11048.36

Table 6.7 - Results of Case 4:-for Height of Backfill 5m for different grades of concrete

Grade of concrete	M 20	M 25	M 30	M 35	M 40
Minimum Cost(INR)	34790.45	36863.88	38758.45	40516.75	42155.39
Optimum Width of base (m)	3.98	4.02	4.05	4.08	4.10
Optimum thickness of base (m)	0.45	0.47	0.48	0.49	0.496
Optimum thickness of stem at bottom (m)	0.35	0.32	0.29	0.28	0.27
Factor of safety provided against overturning	2.57	2.61	2.64	2.67	2.69
Factor of safety provided against sliding	1.58	1.58	1.59	1.60	1.59
Optimum Steel in toe (mm^2)	2573.11	2525.17	2479.23	2437.62	2394.86
Optimum Steel in heel (mm^2)	3398.58	3371.58	3334.47	3294.62	3249.09
Optimum Steel at stem (mm^2)	8849.87	9865.71	10778.50	11613.83	12385.48

Table 6.8 - Results of Case 4:-for Height of Backfill 6m for different grades of concrete

Grade of concrete	M 20	M 25	M 30	M 35	M 40
Minimum Cost(INR)	49113.57	52057.79	54744.27	57232.50	59555.55
Optimum Width of base (m)	4.93	4.97	5.01	5.05	5.08
Optimum thickness of base (m)	0.55	0.56	0.57	0.59	0.60
Optimum thickness of stem at bottom (m)	0.41	0.37	0.35	0.33	0.31
Factor of safety provided against overturning	2.87	2.91	2.95	2.98	3.00
Factor of safety provided against sliding	1.60	1.60	1.61	1.62	1.62
Optimum Steel in toe (mm^2)	3236.09	3183.16	3124.61	3075.25	3024.53
Optimum Steel in heel (mm^2)	4102.78	4076.34	4027.51	3981.78	3928.58
Optimum Steel at stem (mm^2)	10863.60	12109.96	13226.50	14249.91	15194.97

Discussion:-

The program displays the output for a particular height of the soil that has to be supported. The program computes the minimum cost that will incur in the construction of the retaining wall when varying grades of concrete are used. The output displays the minimum cost along with the section and the reinforcement requirement for different grades of concrete starting from M20 to M40. The result gives the dimensions of the section needed on use of a particular grade of concrete. The output gives a cost comparison when different grades of concrete are used.

The result shown here are taken by changing the height of the soil to be retained. In each case the execution of the program gives the output for the minimum cost, dimension of section and the amount of reinforcement required when different grades of concrete are used (M20 to M40).

Case 5:

Input:

Coefficient of friction	= 0.6
Grade of concrete	= M 25
Angle of Backfill	= 18°
Internal Friction angle of backfill soil	= 30°
Unit Weight of Backfill soil	= 18.0 kN/m^3
Unit weight of concrete	= 25.0 kN/m^3
Allowable bearing Pressure	= 160.0 kN/m^2
Internal Angle of foundation soil	= 25°
Unit Weight of foundation soil	= 16.0 kN/m^3
Cost of concrete/cubic meter	= INR 3237.0
Cost of reinforcement per kg	= INR 42.0

Output:

Table 6.9 - Results of Case 5:-for Height of Backfill 4m for different grades of steel

Grade of steel	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	24908.38	17903.20	16011.09
Optimum Width of base (m)	3.19	3.10	3.08
Optimum thickness of base (m)	0.38	0.29	0.26
Optimum thickness of stem at bottom (m)	0.27	0.27	0.27
Factor of safety provided against overturning	2.35	2.24	2.21
Factor of safety provided against sliding	1.56	1.53	1.52
Optimum Steel in toe (mm^2)	1958.12	1586.20	1459.38
Optimum Steel in heel (mm^2)	2688.48	2198.98	2028.92
Optimum Steel at stem (mm^2)	7769.24	4735.30	3934.39

Table 6.10 - Results of Case 5:-for Height of Backfill 4.5m for different grades of steel

Grade of steel	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	30462.11	21790.56	19443.7
Optimum Width of base (m)	3.57	3.47	3.44
Optimum thickness of base (m)	0.42	0.32	0.29
Optimum thickness of stem at bottom (m)	0.29	0.30	0.30
Factor of safety provided against overturning	2.45	2.33	2.30
Factor of safety provided against sliding	1.57	1.54	1.53
Optimum Steel in toe (mm^2)	2221.57	1808.00	1660.20
Optimum Steel in heel (mm^2)	3024.17	2486.32	2289.97
Optimum Steel at stem (mm^2)	8796.64	5370.22	4462.85

Table 6.11 - Results of Case 5:-for Height of Backfill 5m for different grades of steel

Grade of steel	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	36863.88	26272.43	23402.40
Optimum Width of base (m)	4.02	3.91	3.88
Optimum thickness of base (m)	0.47	0.35	0.32
Optimum thickness of stem at bottom (m)	0.32	0.32	0.32
Factor of safety provided against overturning	2.61	2.48	2.45
Factor of safety provided against sliding	1.58	1.55	1.54
Optimum Steel in toe (mm^2)	2525.17	2048.33	1883.78
Optimum Steel in heel (mm^2)	3371.58	2765.32	2551.21
Optimum Steel at stem (mm^2)	9865.71	6028.35	5011.87

Table 6.12 - Results of Case 5:- for Height of Backfill 6m for different grades of steel

Grade of steel	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	52057.79	36895.41	32771.05
Optimum Width of base (m)	4.97	4.84	4.80
Optimum thickness of base (m)	0.56	0.42	0.38
Optimum thickness of stem at bottom (m)	0.37	0.38	0.38
Factor of safety provided against overturning	2.91	2.77	2.73
Factor of safety provided against sliding	1.60	1.56	1.55
Optimum Steel in toe (mm^2)	3183.16	2580.89	2369.28
Optimum Steel in heel (mm^2)	4076.34	3347.30	3084.46
Optimum Steel at stem (mm^2)	12109.96	7415.31	6167.85

Discussion:-

The program here works with the grade of concrete fixed as M25. The input data for the grade of concrete can also be changed. But for a specific grade of concrete the program calculates the minimum cost that will be incurred when different steel is used for reinforcement. It displays the output as the minimum cost that will be incurred when the three types of steel is used, that is, Mild steel (yield strength of 250N/mm^2), High Yield Strength Deformed (steel) (yield strength of 415N/mm^2 and 500N/mm^2). The program computes the sections that satisfy the stability requirement of the retaining wall for particular steel used and then displays the minimum cost and the corresponding section and then it computes the same for the other types of reinforcement then displaying the minimum cost and the dimensions of the sections. Thus the result displayed is the minimum cost and the corresponding section for a particular height of soil retained using the three types of steel reinforcement.

Case 6:

Input:

Coefficient of friction	= 0.6
Angle of Backfill	= 18°
Internal Friction angle of backfill soil	= 30°
Unit Weight of Backfill soil	= 18.0 kN/m^3
Unit weight of concrete	= 25.0 kN/m^3
Allowable bearing Pressure	= 160.0 kN/m^2
Internal Angle of foundation soil	= 25°
Unit Weight of foundation soil	= 16.0 kN/m^3
Cost of concrete/cubic meter	= INR 3237.0
Cost of reinforcement per kg	= INR 42.0

Table 6.13(a) -Results of Case 6 for Height of Backfill 4m for different grades of concrete (M 20 & M 25) & steel

Grade of concrete	M 20			M25		
Grade of steel	Fe 250	Fe 415	Fe 500	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	23542.79	17141.57	15409.13	24908.38	17903.20	16011.09
Optimum Width of base (m)	3.17	3.08	3.06	3.19	3.10	3.08
Optimum thickness of base (m)	0.37	0.28	0.26	0.38	0.29	0.26
Optimum thickness of stem at bottom (m)	0.29	0.29	0.29	0.27	0.27	0.27
Minimum factor of safety against overturning	2.33	2.22	2.19	2.35	2.24	2.21
Minimum factor of safety against sliding	1.56	1.53	1.52	1.56	1.53	1.52
Minimum Steel in toe (mm^2)	1996.66	1607.48	1468.46	1958.12	1586.20	1459.38
Minimum Steel in heel (mm^2)	2706.18	2196.84	2011.86	2688.48	2198.98	2028.92
Minimum Steel at stem (mm^2)	6966.83	4241.31	3521.97	7769.24	4735.30	3934.39

Table 6.13(b) - Results of Case 6:-for Height of Backfill 4m for different grades of concrete (M 30 & M 35) & steel

Grade of concrete	M30			M 35		
Grade of steel	Fe 250	Fe 415	Fe 500	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	26143.51	18602.65	16567.17	27287.83	19259.45	17094.41
Optimum Width of base (m)	3.20	3.11	3.08	3.21	3.11	3.09
Optimum thickness of base (m)	0.38	0.29	0.26	0.39	0.29	0.27
Optimum thickness of stem at bottom (m)	0.25	0.25	0.25	0.24	0.24	0.24
Minimum factor of safety against overturning	2.36	2.24	2.21	2.37	2.25	2.22
Minimum factor of safety against sliding	1.57	1.53	1.52	1.57	1.53	1.52
Optimum Steel in toe (mm^2)	1921.43	1574.18	1445.81	1883.78	1553.85	1430.88
Optimum Steel in heel (mm^2)	2665.64	2207.87	2034.21	2634.59	2198.98	2031.74
Optimum Steel at stem (mm^2)	8491.41	5182.90	4306.31	9150.86	5591.91	4647.45

Table 6.13(c) - Results of Case 6:-for Height of Backfill 4m for M 40 concrete and different grades of steel

Grade of concrete	M 40		
Grade of steel	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	28361.03	19881.82	17596.74
Optimum Width of base (m)	3.22	3.12	3.09
Optimum thickness of base (m)	0.40	0.30	0.27
Optimum thickness of stem at bottom (m)	0.23	0.23	0.23
Factor of provided safety against overturning	2.38	2.25	2.22
Factor of safety provided against sliding	1.57	1.53	1.53
Optimum Steel in toe (mm^2)	1846.54	1539.39	1421.93
Optimum Steel in heel (mm^2)	2598.52	2194.09	2033.87
Optimum Steel at stem (mm^2)	9760.35	5972.98	4965.57

Table 6.14(a) - Results of Case 6:-for Height of Backfill 6m for different grades of concrete (M 20 & M 25) & steel.

Grade of concrete	M20			M 25		
Grade of steel	Fe 250	Fe 415	Fe 500	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	49113.57	35230.90	31448.70	52057.79	36895.41	32771.05
Optimum Width of base (m)	4.93	4.79	4.76	4.97	4.84	4.80
Optimum thickness of base (m)	0.55	0.41	0.37	0.56	0.42	0.38
Optimum thickness of stem at bottom (m)	0.41	0.41	0.41	0.37	0.38	0.38
Factor of safety provided against overturning	2.87	2.74	2.70	2.91	2.77	2.73
Factor of safety provided against sliding	1.60	1.56	1.55	1.60	1.56	1.55
Optimum Steel in toe (mm^2)	3236.09	2602.17	2379.92	3183.16	2580.89	2369.28
Optimum Steel in heel (mm^2)	4102.78	3336.24	3061.26	4076.34	3347.30	3084.46
Optimum Steel at stem (mm^2)	10863.60	6642.09	5522.39	12109.96	7415.31	6167.85

Table 6.14(b) - Results of Case 6:-for Height of Backfill 4m for different grades of concrete (M 30 & M 35) & steel

Grade of concrete	M30			M 35		
Grade of steel	Fe 250	Fe 415	Fe 500	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	54744.27	38443.50	34016.08	57232.50	39890.52	35185.11
Optimum Width of base (m)	5.01	4.87	4.83	5.05	4.89	4.85
Optimum thickness of base (m)	0.57	0.42	0.38	0.59	0.43	0.39
Optimum thickness of stem at bottom (m)	0.35	0.35	0.35	0.33	0.33	0.33
Factor of safety provided against overturning	2.95	2.80	2.76	2.98	2.82	2.78
Factor of safety provided against sliding	1.61	1.56	1.55	1.62	1.57	1.55
Optimum Steel in toe (mm^2)	3124.61	2560.21	2352.89	3075.25	2542.40	2339.59
Optimum Steel in heel (mm^2)	4027.51	3346.82	3087.72	3075.25	3343.04	3088.94
Optimum Steel at stem (mm^2)	13226.50	8112.95	6749.57	14249.91	8753.89	7284.34

Table 6.14(c) - Results of Case 6:-for Height of Backfill 6m for M 40 concrete & different grades of steel

Grade of concrete	M 40		
Grade of steel	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	59555.55	41256.76	36292.23
Optimum Width of base (m)	5.08	4.92	4.87
Optimum thickness of base (m)	0.60	0.43	0.39
Optimum thickness of stem at bottom (m)	0.31	0.31	0.32
Factor of safety provided against overturning	3.00	2.84	2.79
Factor of safety provided against sliding	1.62	1.57	1.56
Optimum Steel in toe (mm^2)	3024.53	2522.27	2330.68
Optimum Steel in heel (mm^2)	3928.58	3330.89	3091.81
Optimum Steel at stem (mm^2)	15194.97	9348.58	7782.46

Discussion:-

The program coding has been done for designing a retaining wall for an inclined backfill. The program computes the minimum cost for all the cases that can be obtained with the combination of the grades of concrete from M20 to M40 and the steel reinforcement. The output displays the minimum cost by using a particular grade of concrete and steel and the corresponding section. The grade of concrete and the steel varies with the other input parameter remaining same for a specific height of soil that has to be retained. The minimum cost is calculated for all the possible cases for a particular height.

The result shows the minimum cost and corresponding section that will satisfy all the check conditions for the various grade of concrete permuted with the types of steel reinforcement. The result here has been shown for various heights of the soil retained but with other input parameters remaining same. Thus cost comparison can be made for which will be a more economical combination. Just using higher grade of concrete may reduce the section but the overall cost may not be reduced.

Case 7:

Input:

Coefficient of friction	= 0.6
Angle of Backfill	= 18°
Internal Friction angle of backfill soil	= 30°
Surcharge load	= 16.0 kN/m^2
Unit Weight of Backfill soil	= 18.0 kN/m^3
Unit weight of concrete	= 25.0 kN/m^3
Allowable bearing Pressure	= 160.0 kN/m^2
Internal Angle of foundation soil	= 25°
Unit Weight of foundation soil	= 16.0 kN/m^3
Cost per cubic meter of M 20 concrete	= INR 3000
Cost per cubic meter of M 25 concrete	= INR 3250
Cost per cubic meter of M 30 concrete	= INR 3500
Cost per cubic meter of M 35 concrete	= INR 3750
Cost per cubic meter of M 40 concrete	= INR 4000
Cost per kg of Fe 250 steel	= INR 40
Cost per kg of Fe 415 steel	= INR 45
Cost per kg of Fe 500 steel	= INR 50

Output: Table 6.15(a) - Results of Case 7:-for Height of Backfill 4m for different grades of concrete (M 20 & M 25) & steel.

Grade of concrete	M 20			M25		
Grade of steel	Fe 250	Fe 415	Fe 500	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	21023.14	16873.90	16192.06	22544.11	17992.57	17233.8
Optimum Width of base (m)	3.69	3.70	3.71	3.67	3.68	3.68
Optimum thickness of base (m)	0.4	0.4	0.4	0.4	0.4	0.4
Optimum thickness of stem at bottom (m)	0.39	0.41	0.41	0.36	0.37	0.38
Minimum factor of safety against overturning	3.01	3.02	3.03	2.98	2.99	3.00
Minimum factor of safety against sliding	1.5	1.5	1.5	1.5	1.50	1.5
Minimum Steel in toe (mm^2)	2317.19	1353.70	1108.21	2342.18	1368.84	1120.77
Minimum Steel in heel (mm^2)	2980.64	1730.69	1412.05	3064.00	1781.09	1454.11
Minimum Steel at stem (mm^2)	5597.38	3162.82	2546.18	6258.06	3536.15	2846.71

Table 6.15(b) - Results of Case 7:-for Height of Backfill 4m for different grades of concrete (M 30 & M 35) & steel.

Grade of concrete	M30			M 35		
Grade of steel	Fe 250	Fe 415	Fe 500	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	23990.22	19080.63	18253.24	25376.59	20138.4	19250.26
Optimum Width of base (m)	3.65	3.66	3.66	3.64	3.65	3.65
Optimum thickness of base (m)	0.4	0.4	0.4	0.4	0.4	0.4
Optimum thickness of stem at bottom (m)	0.34	0.35	0.35	0.32	0.33	0.34
Minimum factor of safety against overturning	2.96	2.97	2.98	2.95	2.95	2.96
Minimum factor of safety against sliding	1.5	1.5	1.5	1.5	1.5	1.5
Optimum Steel in toe (mm^2)	2360.57	1380.11	1130.09	2375.01	1388.79	1137.37
Optimum Steel in heel (mm^2)	3127.12	1819.06	1485.89	3176.8	1849.26	1510.98
Optimum Steel at stem (mm^2)	6855.36	3873.65	3118.42	7404.64	4184.03	3368.28

Table 6.15(c) - Results of Case 7:-for Height of Backfill 4m for different concrete grade M40 & steel.

Grade of concrete	M 40		
Grade of steel	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	26713.62	21170.93	20226.81
Optimum Width of base (m)	3.63	3.63	3.64
Optimum thickness of base (m)	0.4	0.4	0.4
Optimum thickness of stem at bottom (m)	0.31	0.314	0.32
Factor of provided safety against overturning	2.94	2.94	2.94
Factor of safety provided against sliding	1.5	1.5	1.5
Optimum Steel in toe (mm^2)	2386.83	1395.87	1143.3
Optimum Steel in heel (mm^2)	3217.04	1873.8	1531.38
Optimum Steel at stem (mm^2)	7915.9	4472.92	3600.84

Table 6.16(a) - Results of Case 7:-for Height of Backfill 6m for different grades of concrete (M 20 & M 25) & steel.

Grade of concrete	M 20			M25		
Grade of steel	Fe 250	Fe 415	Fe 500	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	42324.36	33156.48	31523.76	45537.77	35366.47	33547.21
Optimum Width of base (m)	5.13	5.02	5.00	5.13	5.01	5.00
Optimum thickness of base (m)	0.58	0.47	0.49	0.56	0.46	0.44
Optimum thickness of stem at bottom (m)	0.57	0.61	0.61	0.52	0.55	0.56
Minimum factor of safety against overturning	3.22	3.10	3.08	3.23	3.09	3.07
Minimum factor of safety against sliding	1.56	1.51	1.51	1.56	1.52	1.51
Minimum Steel in toe (mm^2)	3566.12	2633.27	2261.04	3703.30	2736.25	2365.68
Minimum Steel in heel (mm^2)	4329.03	3233.30	2775.36	4541.05	3413.14	2953.20
Minimum Steel at stem (mm^2)	8632.04	4986.14	4029.44	9672.72	5584.82	4515.05

Table 6.16(b) - Results of Case 7:-for Height of Backfill 6m for different grades of concrete (M 30 & M 35) & steel.

Grade of concrete	M30			M 35		
Grade of steel	Fe 250	Fe 415	Fe 500	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	48616.96	37567.79	35563.37	51531.31	39664.27	37503.32
Optimum Width of base (m)	5.15	5.03	5.01	5.16	5.05	5.03
Optimum thickness of base (m)	0.55	0.45	0.43	0.54	0.44	0.42
Optimum thickness of stem at bottom (m)	0.48	0.51	0.52	0.45	0.48	0.49
Minimum factor of safety against overturning	3.25	3.12	3.09	3.26	3.14	3.11
Minimum factor of safety against sliding	1.57	1.53	1.52	1.58	1.54	1.53
Optimum Steel in toe (mm^2)	3846.48	2849.99	2460.31	3985.86	2960.73	2553.17
Optimum Steel in heel (mm^2)	4728.64	3566.80	3087.49	4909.9	3715.87	3214.02
Optimum Steel at stem (mm^2)	10622.01	6130.23	4954.96	11501.23	6634.77	5361.67

Table 6.16(c) - Results of Case 7:-for Height of Backfill 6m for different concrete grade M40 & steel.

Grade of concrete	M 40		
Grade of steel	Fe 250	Fe 415	Fe 500
Minimum Cost(INR)	54309.08	41676.61	39369.71
Optimum Width of base (m)	5.17	5.06	5.04
Optimum thickness of base (m)	0.53	0.43	0.41
Optimum thickness of stem at bottom (m)	0.43	0.45	0.46
Factor of provided safety against overturning	3.28	3.15	3.12
Factor of safety provided against sliding	1.59	1.54	1.54
Optimum Steel in toe (mm^2)	4124.61	3063.04	2645.62
Optimum Steel in heel (mm^2)	5090.61	3852.49	3338.64
Optimum Steel at stem (mm^2)	12325.55	7105.74	5742.23

Chapter 7

7.1 Conclusion:-

The programming done gives result appropriately. The results showed that with use of higher grade of concrete the dimension of the section reduces but the cost may or may not reduce. This is due to the steel reinforcement requirement in each section. The program runs efficiently in finding out the minimum cost by computing many sections that satisfy the check conditions and displaying the dimension of the corresponding section and the steel requirement in these sections. Shear checks has been incorporated in some of the programs and the section is modified to sustain the shear. The program also included the check for no tension in base condition. The practical approach of design of a retaining wall has been kept in mind and the coding has been done to give a logical design. The provisions of Indian Standard code have been incorporated.

7.2 Future works:

Any work can be improved upon and this project is no different. There is a plethora of scope for developing future programs with certain modifications.

Some of them are mentioned below:

1. Improvement in the program code can be made to incorporate more details like providing trapezoidal section for base slab, clearance between surface of backfill and top of the wall, provision for dynamic loading on surcharge and consideration of effects of rise of water table.

2. The finer provisions of the code IS 456:2000 like provision of development length, clear cover depending upon the environment and bar cut off length among others.

3. Besides, this program code can also be made to design for design standards other than the Indian Standard, if necessary modifications are incorporated.

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