Optimization of Shape Design for Gravity Retaining Walls

Talal Masoud, Hesham Alsharie, Zaydoun Abu Salem, Yasser I. O. Yahia, Manal O. Suliman

Abstract Gravity retaining walls are known to be relatively economic as retaining solution to the heights up to 4m.Gravity walls depend on their mass (stone, concrete) to resist pressure from behind the walls. Many shape gravity retaining walls are used; rectangular, triangular, and trapezoidal. This study focuses on finding the optimum shape design for retaining walls. The cost of the gravity retaining walls depends on the weight and the materials. In order to minimize the cost, materials of the gravity retaining walls should be minimized, which mean that the section of gravity retaining walls must be reduced. The design starts by choosing the shape of gravity walls for which the stability of the wall is checked. To study the effect of shape on minimizing the weight or volume (Area) many sections were used. In the present work the result of a numerical analysis is presented. The results show that the rectangular retaining wall shape has a large volume which in turn it has a large weight equal to100 %from the total weight ,triangular shape has 73 % from the total weight, and trapezoidal shape has 52 % from the total weight with better stability against the soil which is the most economical shape of gravity retaining walls.

Keywords: Gravity Retaining Walls, Shape, Numerical Analysis.

I. INTRODUCTION

Retaining walls are designed to withstand lateral earth and water pressures for a service life based on consideration of the potential long–term effects of material deterioration on each of the material components comprising the wall. Design of retaining structures depends upon the load which is transferred from backfill soil as well as external loads and also the resisting capacity of the structure. For the gravity retaining walls the weight plays the main role to resist against lateral earth pressures. Since the material cost is one of the major factors in the construction of a gravity retaining wall, minimizing the weight or volume of these systems can reduce the cost.

Traditionally, stability control of retaining walls is based on safety factors against bearing capacity, sliding and overturning. Distribution of stress along the wall height is believed to be triangular or, when surcharge load is present, trapezoidal. To mobilize the maximum or the minimum value of stress the observed lateral displacement of the wall should achieve some critical value, which in a real case may not occur.

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Gravity retaining walls are routinely built of concrete or stone and depend primarily on its massive weight to resist failure from overturning and sliding soil mass Previous research suggests different geometry (shape and dimensions) to be used In the present work the effect of geometry (shape and dimensions) and optimization of the gravity retaining walls by numerical analysis is investigated.

In order to economize the cost of the concrete retaining walls under design constraints, it is advantageous for designer to cast the problem as an optimization problem. Optimum design of retaining walls has been the subject of a number of studies. Saribas and Erbatur presented a detailed study on reinforced concrete cantilever retaining walls optimization using cost and weight of walls as objective functions [1]. Ceranic and Fryer proposed an optimization algorithm based on simulated annealing (SA) [2].

Optimization is the process of obtaining the 'best', if it is possible to measure and change what is 'good' or 'bad'. Optimization practice, on the other hand, is the collection of techniques, methods, procedures, and algorithms that can be used to find the optima. Optimization problems are abundant in various fields of engineering, like electrical, mechanical, civil, chemical, and structural engineering. In recent decades, optimization methods have been widely applied to the problems of geotechnical engineering [3,4,5,6,7].

Sivakumar and Munwar in ref. [8] introduced atarget reliability approach (TRA) for design optimization ofretaining walls. Ahmadi and Varaee proposed an optimization algorithm based on the particle swarm optimization(PSO) for optimum design of retaining walls [9].

Ghazavi and Bazzazian Bonab in reference [10] applied a methodology to arrive at the optimal design of concrete retaining wall using the ant colony optimization (ACO).Kaveh et al., [11] used the heuristic big bang–big crunch algorithm (HBB–BC) for the optimum design of gravity retaining walls subjected to seismic loading.

Erol Sadoglu[12] aimed in his study to determine the optimum cross-section outline of a symmetrical gravity retaining wall on granular soil. The cross-sectional area of the plain concrete wall is assumed to be a direct indicator of the cost. Therefore, the objective function is defined as the cross-sectional area. Additionally, the constraints of the optimization problem are derived from the verifications that a concrete gravity retaining wall should satisfy. Thus, the constraint nonlinear optimization problem, defined by the objective function and constraints is obtained.

The problem is solved by developing a computer-program-based interior point method.

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Kaveh et al. at ref. [13] uses the Heuristic Big Bang-Big Crunch Algorithm to determine the optimum design of gravity retaining walls structures. Baziar et al.at ref. [14] studied the sliding stability of gravity retaining walls for the dynamic active case using the pseudo-dynamic method.

Sheikholeslami et al. at ref. [15]developed a novel optimization method namely hybrid firefly algorithm with harmony search technique (IFA–HS), to obtain the optimal cost of the reinforced concrete retaining walls satisfying the stability criteria.

In order to investigate the effect of the shape of the gravity wall; gravity wall with 4m height is used with different shapes. The calculation was carried for each shape separately; and the optimum section for every shape was found [16,17,18]. The engineering aspects that govern the design of a retaining wall are safety, stability, and cost. The optimization for symmetrical gravity retaining walls of different heights is examined in this study. For this purpose, an optimization problem is developed. The weight of the gravity wall provides the required stability against the effects of the retained soil and the ground water. This type of wall is generally constructed of plain concrete and masonry.

II. NUMERICAL CALCULATIONS AND RESULTS

Four different modes of instabilities, namely sliding, overturning, tensile stress, and bearing capacity were checked.

The gravity retaining wall must be safe against all modes if instability. The minimum section should be found; to do that, numerical calculations were carried out using the following:

The unit weight of the soil γ_s =18 KN/m^3

The unit weight of the concrete γ_c =22 KN/ m^3

Coefficient of friction = 0.4 Ka =0.43

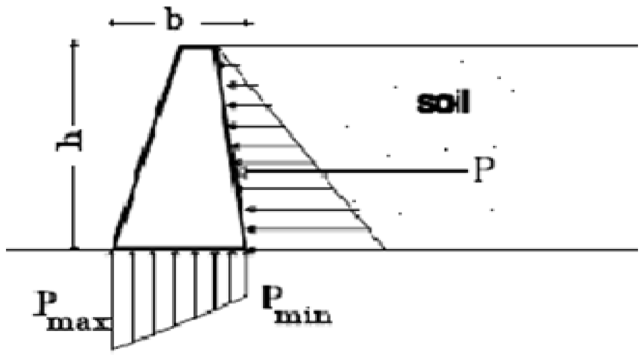
(ϕ) angle of internal fiction of the soil ϕ =25^o and Ka=0.43 and the height =4.0m ,

qu = allowable bearing capacity =160KN/m^2

as showing in figure (1)

Many shape gravity retaining walls are used such as:

1) Rectangular shape
2) Triangular shape
3) Trapezoidal shape



P: Total soil pressure

Pmin: minimum soil reaction

Pmax: maximum soil reaction

Figure (1): Show the Shape of the Gravity Retaining Wall

III. NUMERICAL CALCULATIONS AND RESULT OF ALL OF THESE SHAPES

1. Rectangular shape as showing in figure (2)

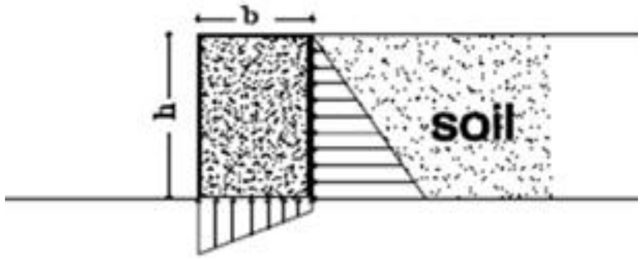


Figure (2): Show the Rectangular Shape of Retaining Wall

A- <u>Design Against tensile stress for Rectangular shape:</u>

We should avoid tensile stress on the gravity retaining wall. In order the tension may not be developed in the base section, it is necessary that the bottom width of the gravity retaining wall is not less than certain limit.

In order that tension may be just avoided the resultant soil pressure (p) and the weight of the wall (w) should strike the base of point (z) such that:

$$z = \frac{2}{3}b$$

$$P = \frac{k_a\ \gamma_s H^2}{2} = 63.072\ KN/m^2$$

$$w = (b)(\gamma_c)(H) = (22)(4)(b) = 88\ b\ KN/m^2$$

$$x = \frac{3b^3}{6b^2} = \frac{1}{2}b$$

$$\frac{2}{3}b = x + \frac{H}{3} * \frac{P}{w}$$

$\frac{2}{3}b = \frac{1}{2}b + \frac{4}{3} * \frac{63.072}{88\ b}$ *then* the bottom width is equal to b = 2.395 m

B- <u>Design Against sliding for Rectangular shape :</u>

µw=P

(0.4) (88) (b)=63.072

then the bottom width is equal to b = 1.792 m

C- <u>Design Against bearing capacity for Rectangular shape:</u>

To be safe against allowable bearing capacity $P_{m(a)}= q_u$

$to\ be\ safe\ \rho_{max=q_u}$, $then\ b = 2.63\ m$

Then to be safe the bottom width should be safe against all modes of instability which mean that must be the largest, b=2.63 m

Then the section area

(4)(2.63)=10.52 m^2

2. Triangular shape as showing in figure (3)

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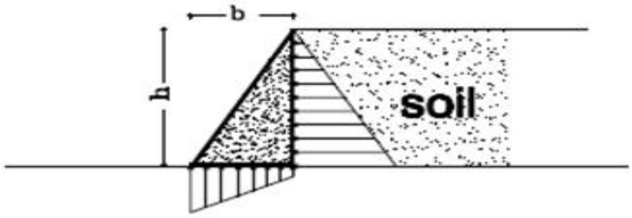

Figure (3): Show the Triangular Shape of Retaining Wall.

A- Design against (tension, tensile stress):

$X = \frac{1}{3}, z = x + \frac{PH}{3w} = \frac{2}{3}$ b, then the width equal to b=2.4 m

B- Design Against sliding:

$\mu w = p$, (0.4) (44 b) =63.072, then the width b=3.584m

C- Design Against bearing capacity:

then (b= 2.63m)

Then to be safe the bottom width should be safe against all modes of instability which mean that must be the largest, b=3.854 m

$$\text{area section} = \frac{(0+3.854)}{2}(4) = 7.708\ m$$

3. Trapezoidal shape as showing in figure (4)

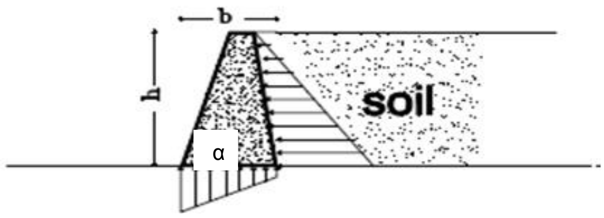

Figure (4): Show the Trapezoidal Shape of Retaining Wall

3.1 When the trapezoidal Section has a vertical soil face that is α = 90 degree

A – design against tensile stress

Take (a= 0.5 m) then (b= 2.209 m)

B – design against sliding

then (b=3.083 m)

C-design against bearing capacity

then (b= 2.63)

Then to be safe the bottom width should be safe against all modes of instability which mean that must be the largest, b=3.083 m then the section area equal to:

$$(\frac{a+b}{2})(H) = (\frac{0.5+3.085}{2})(4) = 7.766\ m^2$$

3.2 With bettered soil face that is α < 90 degree.

A. When the slope $1/5$

Tan α $= \frac{4}{0.8}$

Then α = 78 degree
then , $b = 2.247m$
The section area=$\left(\frac{0.5+2.247}{2}\right)(4) = 5.5m^2$

B. When the slope $1/10$

tan $\alpha = \frac{4}{0.4}$
Then, $\alpha = 84\ degree$
$then\ b = 2.202m$
The section area $= \left(\frac{0.5+2.202}{2}\right)(4) = 5.404\ m^2$

C. When the slope $1/15$

Then $tan\ \alpha = \frac{4}{0.266}$
$\alpha = 86^{\circ}$ $then\ b = 2.2\ m$
then the section $area = 5.4\ m^2$

D. When the slope 1/20

α=87 degree then , $b = 2.22\ m$
The section area= 5.44 m^2

Figure (5) Show the Section Area and the Percentage of the Section Area for all Shapes of the Gravity Retaining Walls

Shape	Section area (m^2)	Percentage section area (%)
1- Rectangular shape	**10.52**	**100%**
2- Triangular shape	**7.708**	**73.2%**
3- Trapezoidal		
	7.166	**68.1%**
$\alpha_2 = 78^{\circ}$ slope $1/5$	**5.5**	**54%**
$\alpha_3 = 84^{\circ}$ slope $1/10$	**5.4**	**51%**
$\alpha_4 = 86^{\circ}$ slope $1/15$	**5.4**	**51%**
$\alpha_5 = 87^{\circ}$ slope $1/20$	**5.44**	**52%**

IV. CONCLUSION

This investigation focuses on the effect of shape on the gravity retaining walls These results show that the rectangular retaining wall shape had a large volume which in turn had a large weight equal to 100 % from the total weight, and triangular shape had 73 % from the total weight and decreased to 52 % from the total weight with trapezoidal shape with batter against the soil which is the most economical shape of gravity retaining walls as shown in figure (6)

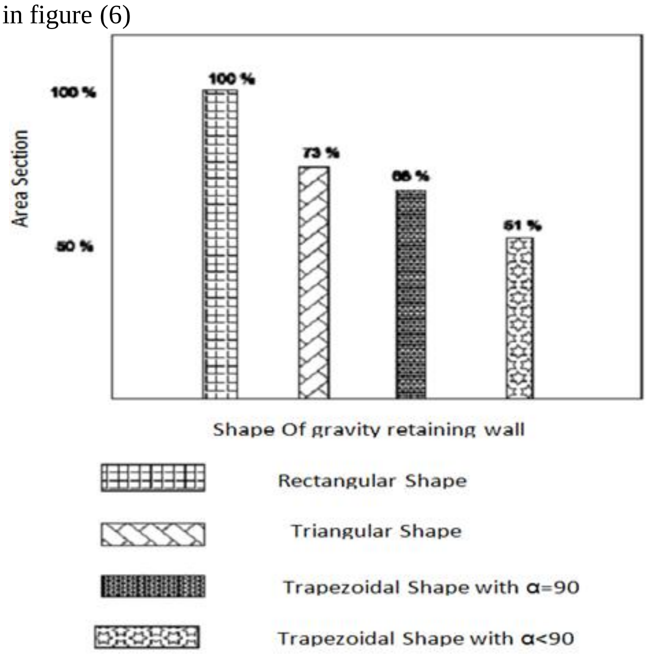

Figure (6)

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