Stability Analysis of Gravity Retaining Walls with Different Wall-back Types under Equal Section Area

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Abstract. Gravity retaining wall is divided into three types: vertical, upward inclined and bent inclined. There are few studies on the stability of different wall-back types of retaining walls. There is no clear regulation on the selection of retaining wall's back types, so it is difficult to measure the economy and rationality. Under the condition that the cross-section area is equal and other external conditions are the same, according to the Coulomb’s earth pressure theory, the anti-slip stability coefficient and anti-overlapping force stability coefficient of different back types of retaining walls are calculated respectively. Through analysis and comparison, the stability of vertical retaining wall is better than other types under the same conditions, which can be preferred.

Keywords: Area of equal cross-section, Different wall- back types, Retaining wall, Stabilization

1. Introduction
In various construction projects, retaining structures are often built to increase system stability. Gravity retaining wall structure is widely used because of its advantages of large section stiffness, good stability increase, simple section type and convenient local materials [1-2]. At present, the design of gravity retaining wall mainly adopts the method of looking up the table, directly applying the set design atlas or drawing up the section size according to the experience, and then calculating and analyzing the strength, stiffness and stability of the structure. The scheme determined by these methods is not an ideal feasible scheme, and the rationality of the scheme depends largely on the designer's experience [3-4]. At present, the research on retaining wall mainly focuses on the analysis method, stress condition and section optimization design of different types of retaining wall, but the research on the stress performance of different types of retaining wall is less [5-7]. At the same time, there is no very clear regulation on the selection of retaining wall type, so it is difficult to measure whether the type selection is economical and reasonable [8-9]. Therefore, it is of great engineering application value to analyze the stress characteristics of different types of retaining walls and select the optimal type under the same conditions.

2. Analysis of Different Types of Retaining Wall

2.1. Fundamental Formulae
1) The active earth pressure is the main load of the retaining wall. The necessary condition for the active earth pressure is that the displacement direction of the retaining wall is the opposite direction along the fill, and there is a certain numerical displacement, which makes the soil behind the wall...
reach a stable equilibrium state. Equations for calculating the active earth pressure $E_a$ of retaining walls are as follows:

$$E_a = 0.5 \rho_1 H^2 K_a$$

$$K_a = \frac{\cos'(\varphi - \alpha)}{\cos^2 \alpha \cos(\alpha + \delta) [1 + \sin(\varphi + \delta) \sin(\varphi - \beta) \sqrt{\cos(\alpha + \delta) \cos(\alpha - \beta)}]^2}$$

$\rho_1$—Bulkweight of backfill behind the wall;
$\varphi$—Inner friction angle of fill material behind wall;
$\alpha$—Wall anticline angle;
$\delta$—The angle between the active earth pressure and the normal direction of the back of the wall;
$\beta$—Tilt angle of fill;
$K_a$—Coefficient of earth pressure.

2) The formula for calculating the anti-slide safety stability coefficient is as follows:

$$K_s = \frac{(G + E_{ay}) \mu}{E_{ax}}$$

$$E_{ax} = E_a \cos(\alpha + \delta)$$

$$E_{ay} = E_a \sin(\alpha + \delta)$$

$\mu$—Friction coefficient of retaining wall base;
$E_{ax}$—Horizontal force of soil pressure;
$E_{ay}$—Vertical distribution of earth pressure.

3) Calculation of Safety Factor for Anti-overturning Stability of Retaining Wall

$$K_t = \frac{Gx_0 + E_{ax}x}{E_{ay}y}$$

$x_0$—Horizontal length of retaining wall center of gravity to bottom of external wall;
$x$—Transverse length of active earth pressure to bottom of external wall;
$y$—Vertical length of active earth pressure to bottom of external wall.

2.2. Main Parameters of Retaining Wall

Combined with an actual project, using three different cross-section shapes, as shown in figure 1, they are: (a) vertical retaining wall, (b) inclined retaining wall, (c) bent inclined retaining wall. Under the condition of equal section area, Retaining wall height $H=4$ m, top width of retaining wall $a=0.6$ m, external friction angle $\delta=15^\circ$, internal friction angle $\varphi=30^\circ$, Angle between slope and horizontal direction $\beta=10^\circ$; Fill weight is $\rho_1$, $\rho_1=20$ KN/m$^3$, $\rho_2$ for wall severity $\rho_2=22$ KN/m$^3$; There is friction between the base line and the foundation plane, Friction coefficient $\mu=0.5$.

![Figure 1. Different types of retaining walls.](image-url)
2.3. Stability Check of Retaining Wall
The stability check of retaining wall includes anti-overturning stability check and anti-slip stability check. The loads acting on the retaining wall include gravity, active earth pressure and foundation reaction.

2.4. Analysis and Calculation

2.4.1. Vertical Retaining Wall. Figure 1(a) shows the cross section shape of vertical retaining wall. Different slope of external wall is drawn up. The stability of retaining wall is shown in figure 2.

As shown in figure 2, Exterior wall slope 1: m, the ordinate is the value of anti-slip stability coefficient $K_s$ and anti-overturning stability coefficient $K_t$. The vertical retaining wall is provided under the same conditions, only the slope ratio is different, and the smaller the slope is at 1: m, the greater the $K_s$ of anti-slip stability coefficient and the $K_t$ of anti-capsizing stability coefficient. As shown in figure 2, when the slope ratio of the external wall is greater than 1:0.4, The anti-slip stability coefficient is less than the specified value, Does not meet $K_s \geq 1.3$, does not meet the requirements. When the slope ratio is 1:0.4 and below, $K_s$ and $K_t$ meet the requirements, the stability of retaining wall is good. Comparison of exterior wall slopes 1:0.4, 1:0.5 and 1:0.6, The smaller the slope, The slower the exterior slope gets, The better the stability of the retaining wall, But the volume of the wall will increase accordingly, 5.9 m$^3$, 6.7 m$^3$ and 7.4 m$^3$. On the premise of retaining wall safety, to minimize the cross section area, when the external wall slope is 1:0.4, the section area of vertical retaining wall is the smallest, The $K_s$ and $K_t$ meet the specifications, At this point, the volume of material used for retaining wall per meter is 5.9 m$^3$.

2.4.2. Upward Inclined Retaining Wall. The wall height $H=4$ m, the wall top width $a=0.6$ m, so the volume of upward inclined retaining wall per meter can be obtained according to geometric calculation. The weight of retaining wall per meter can be determined. The known formula is used to calculate the active earth pressure of the fill, and then calculate the $K_s$ and $K_t$ charts, in which the coordinate is the volume of the retaining wall per meter, the vertical coordinate is $K_s$ and the $K_t$, uses interpolation method to obtain the $K_s$ and $K_t$ when the volume is 5.9 m$^3$.

There are two kinds of calculation results: 1) when the volume of each extension meter is 5.9 m$^3$, the $K_s$ of slip stability coefficient and the anti-overturning stability coefficient $K_t$ at least one of which does not meet the requirements. In this case, the vertical retaining wall is better than the vertical retaining wall. 2) The volume of each meter is 5.9 m$^3$, the two coefficients meet the requirements. If the obtained coefficient is greater than that of the vertical retaining wall, that is, when the slope of the external wall is 1:0.4, the inclined retaining wall is better than the vertical retaining wall. Draw up different inclination angle of the back of the wall $\alpha$, the stability analysis of the retaining wall under
different conditions of inclination angle is shown in figure 3:

**Figure 3.** Anti-slide stability coefficient and anti-capsizing coefficient and anti-capsizing stability coefficient for different inclination angle of wall back

According to the back inclination angle and two coefficient values, the number axis diagram is shown in figure 4, in which the horizontal coordinate is the back inclination angle of the wall $\alpha$, the vertical coordinate is the value $K_t$ the anti-slide stability coefficient and the anti-overturning stability coefficient. Then according to the inclination value of the back of the wall $\alpha$ and the volume value of take the $\alpha$ as the horizontal coordinate and the $V$ as the vertical coordinate as the number axis diagram as shown in figure 4.

According to the analysis, when the slope of external wall is 1:0.6, An absolute value $\alpha$ the back inclination of the wall (the greater the inclination), The smaller the weight of the retaining wall per meter, The less earth pressure behind the wall, The smaller the $K_s$ and $K_t$, The more unstable the retaining wall is. If the retaining wall is 5.9 m$^3$ per meter, Using the interpolation method to figure 4, it can be determined that the back inclination of the inclined retaining wall is about 5.9°. And then -5.9° to figure 3, using interpolation, The available $K_s$ is 1.48, the $K_t$ is 1.95, $K_s$ and $K_t$ meet the requirements, In line with the second result of the problem. The $K_s$ and $K_t$ of the vertical retaining wall are 1.36 and 2.49 per meter, The data show that the two types of retaining walls are superior, Bad judgment.

2.4.3. Bent Inclined Retaining Wall. As shown in figure 1(c), Backward inclination $\alpha$, of bent inclined retaining wall Remember as positive. When the inclination angle of the back of the wall is assumed, the constraint condition is that the inclination angle is generally less than 45°- internal friction angle /2, Should not be greater than 30°, Or it's a wall, The Coulomb earth pressure theory can not be directly applied. The slope of the external wall of the retaining wall is assumed to be 1:0.3, Wall H=4 m, Wall top width $a$=0.6 m, The width of the bottom of the wall $B_3$ varies with the inclination of the back of the wall $\alpha$ (the slope of the inner wall), The analysis process is the same as the inclined retaining wall. Development of different $\alpha$, of back inclination the stability analysis of the retaining wall.
Figure 5. Anti-slide stability coefficient and anti-capsizing coefficient and anti-capsizing stability coefficient for different inclination angle of wall back.

Figure 6. Volume of retaining wall per meter with different inclination.

The broken line diagram is made according to the inclination angle of the back of the wall and the two coefficient values, as shown in figure 5, in which the transverse coordinate is the inclination angle of the back of the wall α, the vertical coordinate is the value of Ks and Kt. Then according to the inclination value of the back of the wall α and the volume value of take the α as the horizontal coordinate, the V as the vertical coordinate as the number axis diagram as shown in figure 5.

According to the analysis of chart information, when the slope of external wall is 1:0.3, The inclination of the back of the wall is calculated as a span of 1°, Contrary to the inclined retaining wall, The values of anti-slide stability coefficient Ks and anti-capsizing stability coefficient Kt obtained are close, And according to the broken line diagram of figure 6, And the bigger the α, The bigger the meter, deadweight G the greater. The greater the active earth pressure behind the wall, The greater the Ks and Kt, The more stable the retaining wall is. If the retaining wall is 5.9 m³ per meter, Using interpolation method to figure 6, it can be determined that the back inclination of the inclined retaining wall is about 7.7, Using 7.7 to figure 6, the Ks is 1.27, the Kt is 2.32, Anti-slide stability coefficient Ks does not meet the requirements, So in the same area, The inclined retaining wall can not meet the stability requirements.

3. Comparison of Different Retaining Walls

Compare the three types of retaining walls with a volume 5.9 m³, and the stability analysis is shown in table 1:

| Type        | 1: m | B/m | α/° | V/m³ | G/kN  | K_a  | E_/kN | K_s  | K_t  |
|-------------|------|-----|-----|------|-------|------|-------|------|------|
| vertical    | 1:0.4| 2.3 | 0   | 5.9  | 129.8 | 0.3431| 54.88 | 1.36 | 2.49 |
| upward      | 1:0.6| 2.65| -5.8| 5.9  | 129.8 | 0.2997| 47.84 | 1.48 | 1.95 |
| bent inclined | 1:0.3| 2.34| 7.7 | 5.9  | 129.8 | 0.4121| 65.81 | 1.28 | 2.32 |

The above analysis shows that when the height of retaining wall H, the friction angle of packing φ, the top width of wall a, the inclined angle of fill β, the bulk density of wall ρ1, the natural bulk density of fill ρ2, the cross-section area of retaining wall are the same. The probability of overturning failure is usually greater than that of sliding failure in the stability checking of gravity retaining wall, and because the greater the anti-overturning stability coefficient, the better the anti-overturning stability is. When both the anti-slide stability coefficient and the anti-overturning stability coefficient meet the requirements, the anti-overturning torque coefficient is preferred, and the vertical retaining wall and
the inclined retaining wall are better $V=5.9 \text{ m}^3$.

4. Conclusion

(1) Three types of gravity retaining wall, under the same cross section area, other external conditions are the same, vertical retaining wall stability is better, can be preferred.

(2) The vertical retaining wall is set under the same conditions, only the slope ratio of the external wall is different, the smaller the slope ratio is $1:m$, the greater the $K_s$ of anti-slide stability coefficient and the $K_t$ of anti-overturning stability coefficient.

(3) When the slope of the inclined retaining wall is fixed, the greater the absolute value $\alpha$ the back inclination of the wall, the smaller the weight of the retaining wall per meter, the smaller the earth pressure behind the wall, the smaller the $K_s$ and $K_t$, the more unstable the retaining wall is.

(4) The larger the absolute value $\alpha$ the back inclination of the inclined retaining wall, the closer the values of the anti-slide stability coefficient $K_s$ and the anti-overturning stability coefficient $K_t$ are obtained.

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