AN APPRAISAL OF THE CURRENT METHOD OF RETAINING WALL ANALYSIS – A CASE STUDY OF CANTILEVERED RETAINING WALLS

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Abstract

Cantilevered retaining walls are important parts of many engineering structures such as basements, bridges, swimming pool, etc. the analysis and design of cantilevered retaining walls have hitherto remained a circuitous and a repetitive process that is error prone. This problem is found mainly in the stability analysis of retaining wall structures. The resulting errors lead to blonder in the choice of reinforcement area and its placement. This paper reviewed the current procedure for the analysis of cantilevered walls and introduced a modification, based on Equivalent Force Systems of Rigid Body Mechanics, and recommended a shorter, error proof, and more straight forward procedure.

Keywords: Retaining structures, stability Analysis, circuitous, error prone, straight forward procedure.

Introduction

Retaining walls are relatively rigid walls used to support a soil mass or a water body There are many types of retaining walls, common examples are cantilevered walls, gravity walls, sheet pile walls, etc. The forces to be resisted by a retaining structure are mainly the lateral pressure of the retained material(Gupta et al,2005)

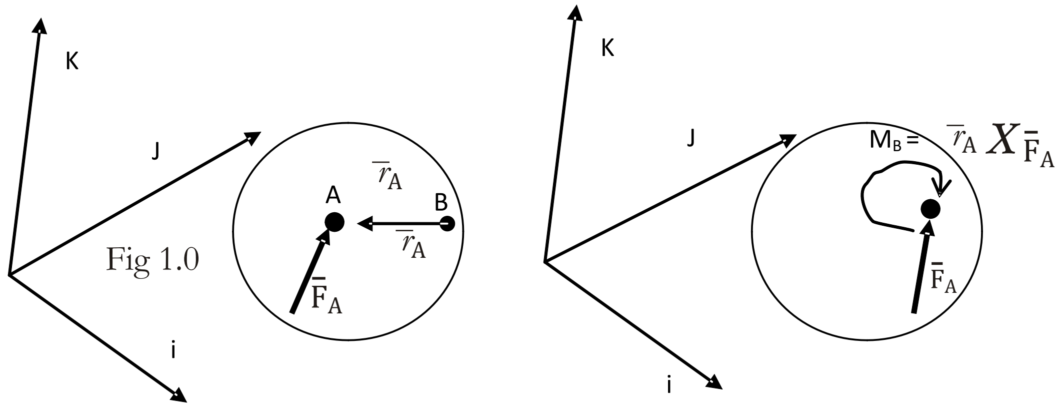
A cantilevered retaining wall is often a masonry structure, well reinforced to retain earth or water. It is found in swimming pools, vertical slope supports in highway structures, foundations in basements, abutments in bridge structures, etc. The status and strategic functions of retaining walls, especially cantilevered walls, as a civil engineering structure requires its analytical procedures to be streamlined and less circuitous, because its failure will always mean the failure of a very important structure.

Analysis of a retaining wall can be divided into two parts: (i) stability analysis where overturning, tilting and sliding are considered, (ii) stress analysis where moment, shear and normal forces are considered. This paper is mainly concerned with the former; this is where the bulk of repetitions and untidy calculation, and the consequent mistakes, are commonly encountered. These mistakes adversely affect the end results of the design, causing wrong selection of reinforcements and its placement at the foundation.

Methodology

Background Theories

Basic principles behind the modification is explained in this section. Consider a rigid body Fig 1.0(i) with a force vector $\bar{F}_A$ applied at point A.



(i) (ii)

An equivalent system of force and moment can be obtained at point B, fig 1.0 (ii), by drawing a radius vector from B to A, such that the vector product $\overline{M}_B = \overline{r}_A \times \overline{F}_A$, and $\overline{F}_A = \overline{F}_B$ in magnitude and direction. The two force systems in fig1 (i) and fig1 (ii) are considered equivalent in Rigid Body Mechanics (Ferdinand et al, 2011). Applying this principle to the structure in fig 2.0, three equivalent systems can be produced as shown in fig 2.0(i), fig 2.0(ii) and fig 2.0(iii).

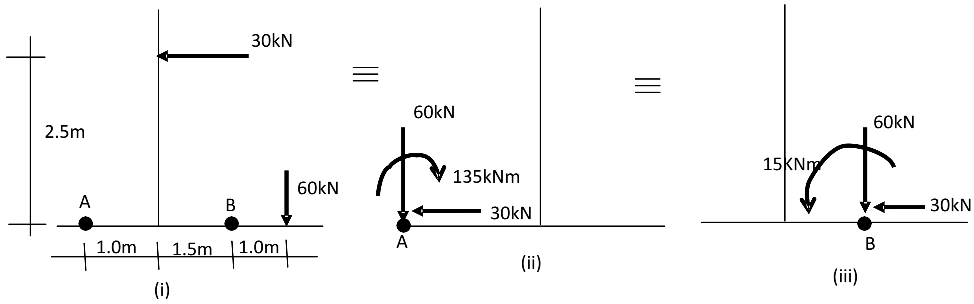


Fig 2.0

Fig 2.0 (ii) is obtained by summing moments of all the forces at point A and transferring the forces parallel to their original directions to A (i.e. 135 = 3.5 x 60 – 2.5 x 30). Fig 2.0 (iii) is obtained by making use of the forces and moment at point A ,fig 2.0 (ii) ,such that 15kNm = 60 x 2.5 – 135, and transferring these forces parallel to their original directions to point B. The reader can equally check to see that fig 2.0 (iii) can be obtained directly from fig 2.0 (i) – i.e 30kN x 2.5m – 60kN x 1.0m = 15kNm followed by the necessary movement of the forces. From the point of view of statics, these force systems are the same and can be used interchangeably.

2.2 Example Calculation Base on the Proposed Method

Consider a retaining structure – a bridge abutment shown in fig 3.0, with the following dimensions, loading and soil properties:

(i) Unit weight of granular backfill = 18.0kN/m3
(ii) Friction angle of backfill and foundation soil Ø
(iii) Coefficient of fiction at the base μ = 0.53 or tanØ
(iiI) Factors of safety against sliding and overturning = 1.5
(v) Load from bridge deck PM = 488kN
(vi) Load from braking and skidding of vehicular traffic = 302.47kN
(vii) Bearing capacity of foundation soil = 350kN/m2

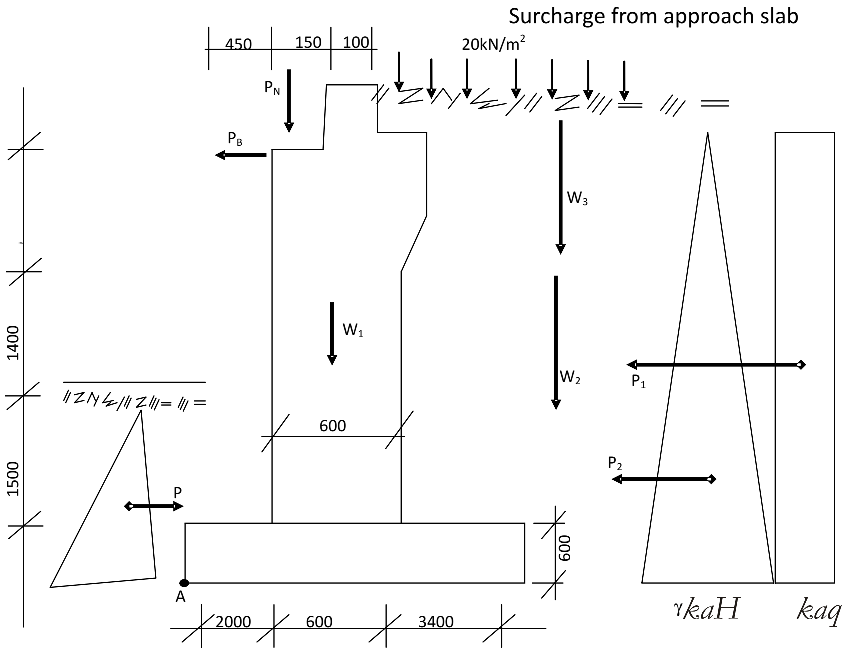


Fig 3.0 Bridge abutment with the usual loadings

Stability Analysis

(i) Overturning

$$Ka = \frac{1-\text{SinØ}}{1+\text{SinØ}} = \frac{1-\text{Sin }30}{1+\text{Sin }30} = 0.33$$

$$Kp = \frac{1+\text{SinØ}}{1-\text{SinØ}} = \frac{1+\text{Sin }30}{1-\text{Sin }30} = 3.0$$

Table 1.0 Disturbing forces (horizontal forces)

S/N	Description of force/symbol	calculation	value of force
1	total active pressure from backfill P_1	$\frac{1}{2}\gamma ka H^2 = 0.5 \times 18 \times 0.33 \times 4.6^2$	62.86 kN
2	Total active pressure due to surcharge P_2	qkaH = 20 x 0.33 x 4.6	30.36KM
3	total passive pressure at the face of the wall P_P	$\frac{1}{2}\gamma kpZ^2 = 0.5 \times 18 \times 3.0 \times 1.5^2$	- 60.75kN
4	horizontal force due to skidding and braking of vehicles		270kN
	Total ($\sum Fx$)		302.47

Disturbing Moment $\sum M_A = -62.86\ (1.7 + 1.4 + 1.5)\ \frac{1}{3}$

$- 30.36\ (1.7 + 1.4 + 1.5)\ \frac{1}{2}$

$+ 60.75 \times 0.5 - 270\ (1.4+15)$

$= -$ 918.84kNm (anticlockwise)

Table 2.0 Restoring forces (vertical forces)

S/N	Description of force/symbol	calculation	value of force
1	Axial load from superstructure		488kN
2	weight of stem W_1	0.6 x 1.0 x 4.6 x 24.kN/m³	66.24kN
3	weight of backfill W_2	3.4 x 4.6 x 1.0 x 18	281.52kN
4	Weight of surcharge W_3	20 x 3.4	68KN
5	weight of concrete base	0.6 x 6.0 x 1.0 x 24	86.4 kM
	total ($\sum fy$)		990.16kN

Restoring moment $\sum M_A =$ 488 (2.0 + 0.45)

$+66.24\ (2.0+0.3)$

$+281.52(6.0-\frac{3.4}{2})$

$+ 68\ (6.0 - \frac{3.4}{2})$

$+ 86.4\ (6.0 -3)$

= 3000.19kNM (clockwise)

Overturning checks:

$$\frac{\text{Restoring moment}}{\text{Disturbing moment}} = \frac{3000.19\text{kNm}}{918.84\text{kNm}}$$

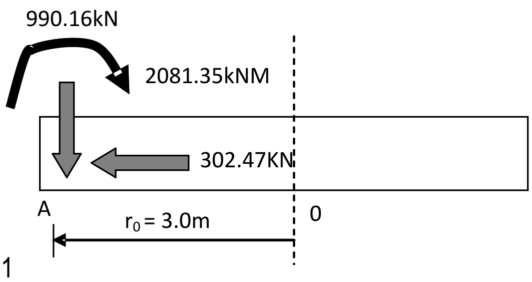
= 3.265 >>1.5

Structure is secured against overturning.

(ii) Tilting

Tilting occurs when the foundation pressure exceeds the soil bearing capacity. To be able to check this, there is need to determine the pressure distribution under the base of the retaining wall, which requires summing moments of all the forces (horizontal and vertical forces) acting on the structure about the centerline of the base. If one should insist on the statuesque, then there is need to calculate new lever-arms for all the forces and sum their moments about the base centerline, which is burdensome. This can be circumvent, however, by adopting the new approach, i.e summing moments of all the forces about the toe and reducing same to the centerline of the base as explain in the foregoing, i.e

Total MA = 3000.19 kNM – 918.84 kNm
= 2081.35 (see fig 4.0)

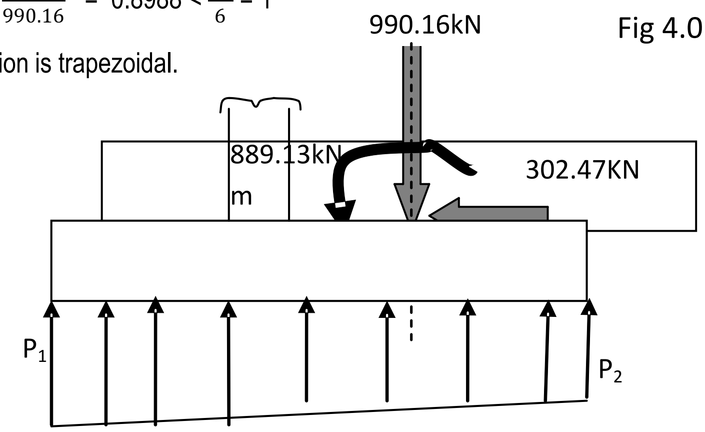


M_o = - 3.0 x 990.16 + 2081.35
= - 889.13 (see fig 5.0)

$e = \frac{M_o}{F_y} = \frac{889.13}{990.16} = 0.8988 < \frac{L_B}{6} = 1$

Fig 4.0

Pressure distribution is trapezoidal.



$P_{1,2} = \frac{F_y}{L_B} \pm \frac{6M_o}{L_B^2}$ L_B = 6.0

$P_1 = \frac{990.16}{6.0} + \frac{6 \times 889.13}{6^2}$

= 313.215 < 350kN/m^2

Structure is secured against tilting

iii) Sliding

Sliding occurs when the ratio of frictional force under the base to that of the total horizontal forces is less than the factor of safety, i.e

$$\frac{\mu \quad F_y}{F_x} = \frac{0.53 \times 990.16}{302.47KN}$$

$$=1.74>1.5$$

Structure secured against sliding

Discussion of Results

The difference between the above method and the usual method is that summation of the moment of all the forces about the base centerline, a necessary condition for checking tilting, is done without calculating new lever-arm and summing moments of all the forces again, which constitutes repetitions, and could result in mistakes such as mixing up of signs, omitting of one force or the other etc. The effects of such mistakes is felt in the calculation of soil upward pressure distribution, i.e it could wrongly be calculated as triangular distribution to the extent that there may falsely be tension at the top of the foundation. This further course faulty moment values, and finally wrong choice of reinforcement and its placement.

Conclusion and Recommendation

It is clearly understood that the usual method is mistake prone, and that the method demonstrated here is shorter and time saving. It is therefore recommended to both student and practicing engineers to use this to reduce costly mistakes in the design of retaining walls.

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