Stability of Cantilever Rigid Retaining Walls Backfilled With Sand-Geofoam Beads Mixture

[Saiedeh Baghanian, Mohammad Reza Arvin]

***Abstract*—This paper studies the effects of using sand-geofoam beads mixture as the backfill of cantilever rigid retaining walls on the factor of safeties against possible modes of failure. With this regard, concrete walls with specified geometrical properties are assumed and backfill material properties are extracted from a previously achieved research work. Factor of safeties against failure modes including transitional, overturning and deep-seated for different heights of wall and geofoam-sand mass ratio were obtained. Results show that unlike gravity rigid retaining walls backfilled with the sand-geofoam beads, cantilever walls don't follow a steadily increasing trend in two of the failure mode's factor of safeties.**

***Keywords*—rigid contilever retaining wall, sand-geofoam beed mixture, stability, factor of safety**

I. Introduction

Geosynthetics are planes made of polymeric materials and are used extensively to solve the geotechnical problems nowadays. The most important properties of these products is that due to their high resistance against corrosion, can be used as buried elements inside the soils. In addition, the low specific mass and high strength of geosynthetics help them to be utilized for problematic subgrades. These products are used for reinforcement, isolation, drainage and so on and have many contributions to foundations, retaining walls, slopes, pavements and bridge piers.

Geofoams as one of the members of geosynthetic family, are classified as lightweight material due to their low specific weight. As a whole, because of the light weight, minor volume change in the vicinity of water, small permeability and relatively appropriate strength of geofoams, their popularity in geotechnical practice are growing. Geofoams are being applied in embankments, backfill of retaining walls, slope stability and lightweight concrete. The first use of geofoams dates back to 1970 in Norway where it was applied to retrofit a bridge abutment [1].

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Geofoams are crucial to decrease the excessive settlement of embankments overlying the soft subgrades, lateral displacement in retaining walls and inhibition of connection failure of flexible pipelines.

The pressure strength of geofoams ranges between 70 to 350 kPa. Geofoams are so light compare to soil so that their density is around 1% of that of soils. According to ASTM, mass density of geofoams lies between 11.2 to 45.7 kg/m^3. Maximum compression strength of geofoams in 1%, 5% and 10% compressive strains are 128, 300 and 345 kPa respectively for ρ=45.7 kg/m^3. Because of the high inflammability of geofoams in high temperature, they must be kept and stored with caution. Geofoams are usually applied in practice in the form of blocks made in different sizes and strengths. Blocks of geofoams are generally produced in limited dimensions, namely 1.25 m width, 0.1 to 1 m thickness and 0.5 to 5.6 m height. Index properties of geofoams including unit weight, elastic modulus and stress-strain behavior under compressive loads plus their behavior in combination with lightweight concrete and expandable soils have been investigated in variety of research works. Negussey [2], conducting unconfined compressive strength tests on 50 mm cubic samples, observed that increasing the unit weight of geofoam results in increase in compression strength and elastic modulus. Studies show that geofoams diminish the problems associated with expansibility of expansive clays. Aytekin et al. [3] performed a number of tests on expansive soils, without and in combination to geofoam roles. In different thickness and obtained the lateral and normal swelling pressure. The most important finding of their investigation is that applying geofoam roles in conjunction with expansive clay, decrease lateral and normal soil swelling pressure while the effect on lateral pressure is more vital.

Although the use of geofoms in the forms other than big blocks are not widespread, considerable volume of geoafoams in urban and industrial waste materials remained from food packing and goods, justify the use of these products in small dimensions down to bead size. Furthermore, it is not appropriate to use geofoams in small and inaccessible places. Deng and Xiao [4] conducted a series of drained triaxial and direct shear tests on pure sand and mixture of sand-geofoam beads with different mass ratio, i.e. ξ=0.5%, 1.5% and 2.5%. They used semi compacted and well graded sand. The normal stresses applied in their test were 100, 200, 300 and 400 kPa. The followings are their main conclusions:

1) Existence of geofoam beads close to sand particles leads to considerable decrease in friction angle of the mixture, particularly in lower mass ratios.

2) Geofoam beads cause apparent cohesion and overconsolidation behavior in sand-geofoam beads mixture.

3) Compare to pure sand, the mixtures of sand and geofoam are more compressible.

4) Results from triaxial tests show that for lower mass ratio of mixture, the Mohr-Coulomb failure criteria is linear as opposed to piecewise linear at high mass ratios.

Soil retaining structures are extremely widespread and important in civil engineering projects. These structures and evaluation of their stability, triggered the premier theories of plasticity [5]. Retaining walls are classified to two main groups, namely rigid and flexible walls. While flexural strength is the predominant design criterion for flexible walls, forces caused by backfill and wall weight, determine the design of rigid walls. Rigid retaining walls, are grouped to cantilever and gravity walls. The main difference of the foregoing walls is that for cantilever rigid walls, weight of back fill has a major role in the wall stability while it does not much effect on gravity walls.

The kind of backfill material has great effects on the lateral pressure imposed on the wall and its design. Since the back space of the walls are mostly irregular geometrically, it is reasonable to use flexible sand-geofoam beads mixture as a backfill material to fill all voids.

Using lightweight backfill materials such as sand-geofoam beads, certainly decrease the normal and in consequence, lateral pressure imposed on the wall which in turn may lead to improvement of wall behavior. Baghanian and Arvin [6] investigated the stability of gravity rigid retaining walls with sand-geofoam beads backfill and determined the safety factors against transition, rotation and deep-seated failure. Of their main findings are the follows:

a) Increase in geofoam to sand mass ratio (ξ) enhance the factor of safeties of all modes of failure.

b) The amount of increase in transition and deep-seate factor of safeties are abviously more than that of rotational failure.

c) Due to linear relation among geometrical dimensions of walls under consideration, changes in wall height do not affect the rotational factor of safety for different mass ratio (ξ).

d) For a constant ξ, transitional and deep-seated safety factors increase with reduction of wall height.

As far as authors know, the stability of rigid cantilever walls backfield by sand-geofoam beads has not been investigated so far. Diagram of possible loads on a typical rigid cantilever wall is illustrated in Figure 1.

The passive resisting force on the front face of the wall is neglected in this study in view of safety enhancement. The present study, investigate the effects of sand-geofoam beads mixture as a backfill on the safety factor of different failure modes of rigid cantilever walls. Required properties of sand-geofoam beads mixture have been extracted from Deng and Xiao [4] research work.

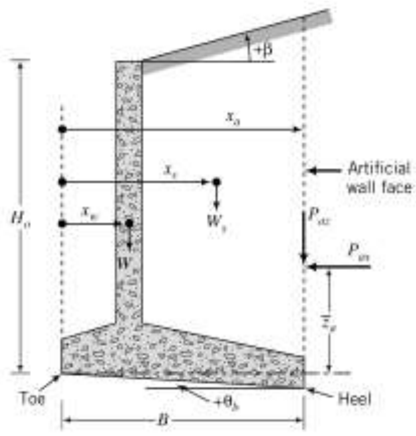


Figure 1. a typical rigid cantilever retaining wall [7]

II. Stability of rigid cantilever retaining walls

In this study, Coulomb lateral earth pressure coefficient [5] modified by Puncelt [8] was implemented where the friction angle of the wall-backfill interface is δ, ground inclination angle is β and inclination of the back face of the wall with respect to vertical line is η. The foregoing relation is as follow:

$$K_{ac} = \frac{\cos^2(\phi' - \eta)}{\cos^2\eta \cos(\eta + \delta)\left[1 + \left\{\frac{\sin(\phi' + \delta)\sin(\phi' - \beta)}{\cos(\eta + \delta)\cos(\eta - \beta)}\right\}^{1/2}\right]^2} \quad (1)$$

In equation 1, K_{ac} is Coulomb active lateral earth pressure coefficient and ϕ' denotes the drained friction angle of backfill material. Walls must be stable against possible failure modes. Therefore, all likely failure modes must be considered and the wall safety against them be evaluated. Rigid retaining walls poses four failure modes namely, transition, rotation around toe, deep seated and structural failures.

In order to prevent the wall from transition, they must resist against sliding of the base. Factor of safety against transition is attained as the ratio of resisting (F_r) to driving (F_d) forces shown in Figure 1 as the following equation:

$$(FS)_T = \frac{[(W_w + Ws + P_{az})\cos\theta_b + P_{ax}\sin\theta_b]\tan\phi'_b + S_w B/\cos\theta_b}{P_{ax}\cos\theta_b - (W_w + Ws + P_{az})\sin\theta_b} \quad (2)$$

In the equation 2, θ_b denotes wall base inclination angle which is taken zero in the present study. Friction angle of the wall base-base soil interface is denoted by ϕ'_b . Adhesion of the base of the wall and underlying soil is denoted by s_w where here is taken 0.6 c (soil cohesion). In addition, P_{ax} and P_{az} are lateral and vertical components of backfill active lateral earth force respectively and can be calculated by the following relations:

$$P_{aC} = \frac{1}{2}K_{aC}\gamma H_0^2$$
$$P_{ax} = P_{aC}\cos(\delta + \eta) \quad (3)$$
$$P_{az} = P_{aC}\sin(\delta + \eta)$$

It should be noted that the friction angle at the wall-backfill interface (δ) generally are assumed to be 0.5 ϕ′ to 0.67 ϕ′ and similarly ϕ_b' is taken as 0.5 $\phi_{base\ soil}'$ to 0.67 $\phi_{base\ soil}'$. The same ratios are held between adhesion of the wall-base soil adhesion and cohesion of the base soil.

The rigid retaining wall is stable against overturning provided the overturning factor of safety is higher than 1.5 to 2. The overturning factor of safety is obtained from the ratio of resisting to driving moments around toe as follows:

$$(FS)_{overturning} = \frac{\Sigma M_R}{\Sigma M_d} = \frac{P_{az}\,x_a + W_S x_s + W_w\,x_w}{P_{ax}\,\bar{z}_a} \qquad (4)$$

In equation 4, x_a, x_w, x_s and z_a are the arms of vertical active force, Wall weight force, soil weight force and horizontal active force respectively.

Stability of the wall against deep seated failure must also be evaluated. In this regard, typical limit equilibrium methods e.g. Janbu, Morgenstern-Price, Bishop and ordinary methods can be employed. Several softwares available to achieve this task. In the present study, Geo-Slope software is utilized.

III. Properties of wall and backfill

Geometrical properties of the wall considered in the present study, has been depicted in Figure 2.

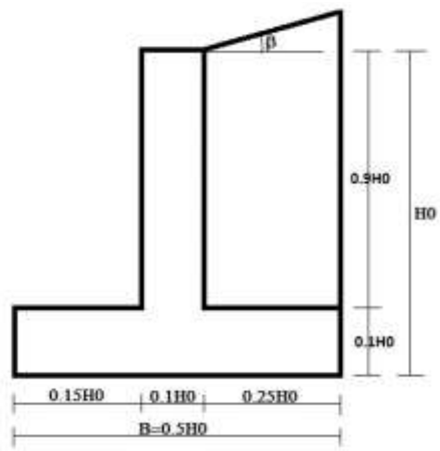


Figure 2. Geometrical properties of the rigid cantilever retaining wall Considered in the present study

As depicted in Figure 2, the height of the wall (crest to the base) is denoted by H_0. In this study, results are presented for four different measures of H_0, namely H_0=2, 3, 4 and 5m. Comparing the Figures 1 and 2, it is obvious that in the present study, wall faces are assumed to be vertical so that the angles η and λ both take zero value. Besides, β and θ_b are assumed to be 10° and 0° respectively. Friction angle at the interface of wall base and the base soil is taken 0.6$\phi_{base\ soil}'$. Furthermore, δ is assumed to be equal to 0.6 ϕ′.

Wall considered to be made of concrete, where the concrete unit weight is γ_c=24 kN/m^3. Properties of the backfill material considered in this study, are extracted from the research done by Deng and Xiao [4] and are illustrated in Table 1.

Table 1. Properties of the wall backfill material

ξ (%)	γ (kN/m3)	c (kN/m2)	ϕ′(°)
0	18.7	5	32.6
0.5	12.6	8	26.7
1.5	8.2	15.5	24.7
2.5	6.3	18	21.8

It should be noted that backfill strength parameters depicted in Table 1 are the results of the direct shear tests that is reasonable to use in this study due to plain strain conditions of the considered wall.

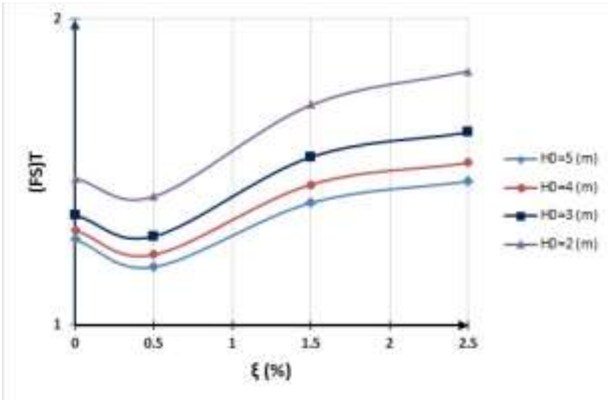
IV. Results

Based on the geometrical and the material properties attributed to wall, foundation and backfill, the wall safety factors against transition and overturning failures determined using equations 1 to 4 for H0=2,3,4 and 5 m. The factor of safeties against transitional and overturning failures are illustrated in table 2 for H0=5m and in Figure 3 for all wall heights considered in this study.

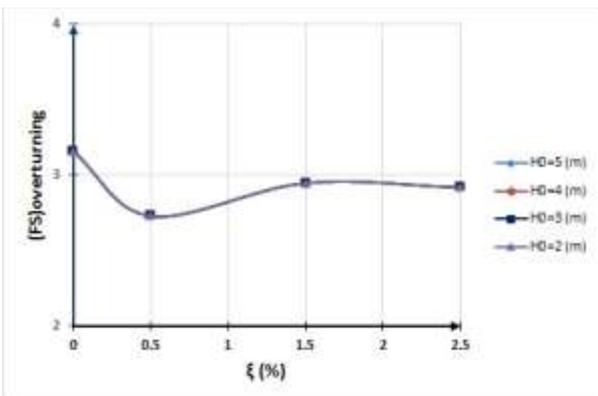
Table 2. Transitional and overturning factor of safety for H_0=5 m.

ξ ((%)	$(FS)_T$	$(FS)_{overturning}$
0	1.28	3.16
0.5	1.19	2.73
1.5	1.4	2.95
2.5	1.47	2.92

Stability of the wall against deep seated failure was evaluated by modeling the wall in Geo-Slope software and determining the factor of safety of the wall against overall stability. Walls of different heights (2, 3, 4 and 5 m) and different geofoam-soil mass ratio (ξ=0%, 0.5%, 1.5%, 2.5%) were modeled and analyzed by well-known methods of slices including Morgenstern-Price, Janbu, Bishop and Ordinary to find their overall factor of safety.



(a)

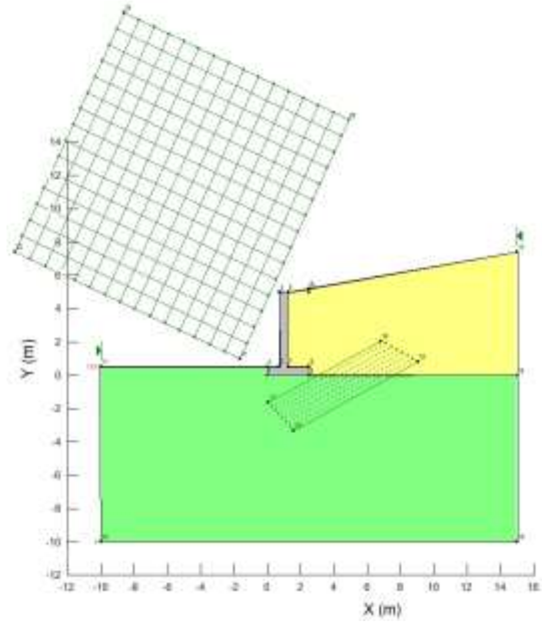


(b)

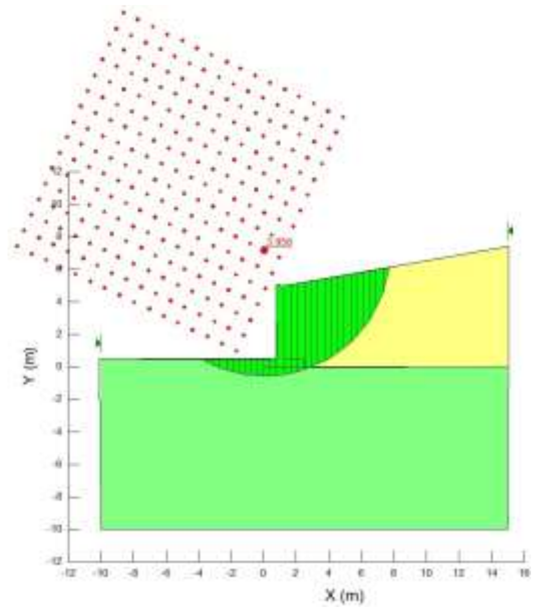
Figure 3. (a) Transitional Safety factor. (b) Overurning safety factor

Figure 4(a) depicts the modeled wall in Geo-Slope. Factor of safety against deep seated failure for H_0=5 and different mass ratio by different method of slices can be observed in Table 3. Furthermore deep seated factor of safeties by Janbu method are shown in Figure 4(b).

As Figure 3.a shows, regardless of the wall height, adding the geofoam beads to sand up to ξ=0.5% , leads to decrease in the safety factors against overturning and transition failure. The trend is different for higher values of geofoam-sand mass ratio so that, transitional factor of safety begins to go up from ξ=0.5% and keeps increasing up to ξ=2.5%, while overturning factor of safety first increase from ξ=0.5% to ξ=1.5% and have a relatively constant value from ξ=1.5% to ξ=2.5%. The minimum values of both transition and overturning failures are obtained at ξ=0.5%. The maximum value of FS_T can be observed for H0=2m and ξ=2.5%.



(a)



(b)

Figure 4. (a) Model of contilever wall and backfill in Geo-Slope.

(b) Slip surace and associated factor of safety for H_0=5 m.

Table 3. factor of safety against deep seated failure for H_0=5 m

ξ (%)	(FS)df (Morgenstern-Price)	(FS)df (Janbu)	(FS)df (Bishop)	(FS)df (ordinary)
0	1.897	1.652	1.899	1.650
0.5	2.204	1.945	2.185	1.992
1.5	3.196	3.083	3.189	3.061
2.5	3.96	3.944	3.973	3.871

Results of safety factor against deep seated failure for all wall height and different geofoam-sand mass ratios considered herein are shown in Figure 5.

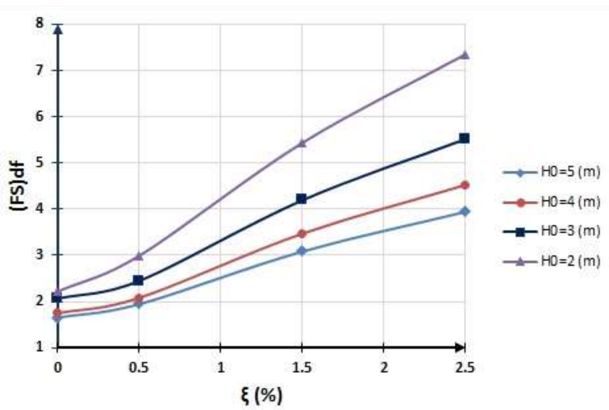


Figure 5. Factor of safety against deep-seated failure by Janbo method

Transitional factor of safety is conversely related to wall height as Figure 3(a) shows. The same is not true for overturning factor of safety, i.e. overturning factor of safety is independent of wall height (Figure 3(b)). This can be attributed to the linear relationship between different wall dimensions as illustrated in Figure 2, so that resisting and driving moments change at the same ratio as wall height varies.

As Figure 5 shows, the variation of deep-seated failure factor of safety (FS_{ds}) versus ξ are always increasing. This is in contrary to fluctuating trend of transitional and overturning factor of safeties (Figure 3). However, FS_{ds} increase gently between ξ=0% to ξ=0.5% and goes up sharply beyond ξ=0.5%. Similar to transitional failure, overturning factor of safety is conversely related to wall height.

V. Conclusions

In order to evaluate the effects of sand-geofoam beads mixture on the stability of cantilever rigid retaining wall, a wall geometrically identical to Figure 2 is considered and its factor of safeties against possible modes of failure were determined for pure sand and backfill made of different mass ratio of geofoam beads to sand (ξ=0%, 0.5%, 1.5%, 2.5%). The main findings are as follows:

1) In comparison to rigid gravity retaining wall backfilled with sand geofoam beads mixture [6], factor of safeties against different modes of failure follow multifold trends.

2) Factor of safeties against transitional failure show a decreasing trend from ξ=0% to ξ=0.5% and start to increase beyond ξ=0.5%.

3) Overturning factor of safety first increase from ξ=0.5% to ξ=1.5% and have a relatively constant value from ξ=1.5% to ξ=2.5%.

4) ξ=0.5% can be considered as a critical value, since minimal values if transitional and overturning factor of safeties are obtained in this ratio.

5) The deep-seated failure factor of safety always increase with increasing ξ.

6) Due to linear dependency of different dimensions of the cantilever walls under consideration, overturning factor of safety is independent of wall height.

7) Deep-seated and transitional factor of safeties are conversely related to wall height.

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