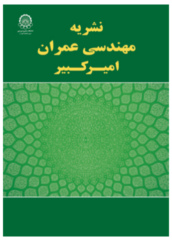

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Estimation of Lateral Forces on Retaining Walls Adjacent to Layered Embankments in Saturated and non-Saturated Conditions

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ABSTRACT: Investigation of development behavior and the dimensions of the embankments behind retaining walls explains the effect of the movement of the wall and its destructing effect. Majority of the natural embankments are layered and are usually in saturated condition. Hence, this research investigates the failure wedge caused by the wall's rotation around the heel. Physical measurements were performed in order to provide data to use the graphical approach of calculation of lateral pressure of layered embankments in both saturated and non-saturated conditions. Thus, 4 layering models were tested including: 1) two layered (upper layer: clay, bottom layer: sand), 2) two layered (upper layer: sand, bottom layer: clay), 3) three layered (upper layer: sand, middle layer: clay, bottom layer: sand) and 4) a for layered model (upper layer: clay, first middle layer: sand, second middle layer: clay, bottom layer: sand). Elevation of layers in each layering model were determined to be equal. Results indicated that using common theoretical methods will result in a conservative design for walls which increases the construction costs. Absence of the failure wedge at wall toe as well as the 32.75% and 29.25% difference between experimental results to theoretical results of Rankin and Sirnivasa methods are other evidence for the conservative design of walls using common methods.

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1- Introduction

In rigid retaining walls, deformations of the body is negligible. Hence, forces which act on wall are dependent to the displacements of the wall. Rigid walls are used in construction of various engineering structures such as bridges, road and surge channels. Cantilever wall and buttress are well known examples of this kind of wall. Buried cantilever walls are used mostly when the deformations of soil are important or the available work space is limited. Stability and resistance of these walls against lateral drift of soil and other external forces would be supplied by their bending strength and their depth of penetration in soil [1]. The dynamic behavior of such walls are dependent to the geometrical and mechanical characteristics of soil and wall as well as the soil-wall interactions. Retaining structures including retaining walls, buried walls and coastal walls which are used to protect the soil slopes, are under the impression of the propulsive forces of soil. Proper design of these walls require an exact estimation of the lateral pressure between soil and wall. Lateral force is a force applied on structures by soil which is caused by soil weight and the dead or live loads. Magnitude of these lateral forces are a function of physical parameters of soil, soil-structure interaction and the extent of relative and absolute displacement of wall. Various methods are proposed by researches however, the Magnitude and the distribution of static lateral pressures are still unknown due to passiveness of the applied pressure by a single particle and the absolute internal forces of particles. Rao et al., (2015) investigated the effect of adhesive soils on their active pressure on retaining walls. Results showed that decreasing the lateral active pressure on wall would be accompanied by increase in the friction angle of soil and wall [3]. Chen (2014) presented a novel analytical method based on limit equilibrium to calculate the active pressure of soil on wall. He concluded that the distribution of pressure behind the wall is nonlinear and the location of the impact of the active pressure is slightly higher than 1/3 of the walls height which is different from Columbus theory [2]. Benembark et al., (2016) investigated the active pressure of soil on wall in various conditions of wall displacement using the Finite Difference method and FLAC software. They inferred that in hydrostatic pressure conditions, displacement of the wall toe matches laboratory results [4].

Review of past literature, showed that the majority of researches have been carried out in homogenous and dry embankments. But, it should be noted that homogenous and dry soils are rarely found in nature so that most of soils are layered and mostly saturated due to their proximity to underground water reservoirs. So this research considers investigation of lateral forces acting on the layered soils in both saturated and unsaturated conditions.

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2- Methodology

Experiments were carried out in a laboratory model built in the laboratory of physical modeling in Shahid Chamran University of Ahvaz. The length, width and height of this model were equal to1 meter, 0.35 meter and 1 meter respectively. In this a model cantilever retaining model was designed, built and installed in the middle of lab flume. Frame of the model was made utilizing 4 mm thick sheets in 3 directions. An 8 mm glass was used for the other side to provide the ability of observing the process of soil deformation during the tests and exporting data. The scale of simulated retaining wall to a real wall in nature is 1 to 10. Hence, utilizing optimized wall analysis a model with height of 5 meter and specific weight of embankment equal to 20K newton per cubic meter is simulated. Figure 1 presents a schematic view of the laboratory model used in this study.

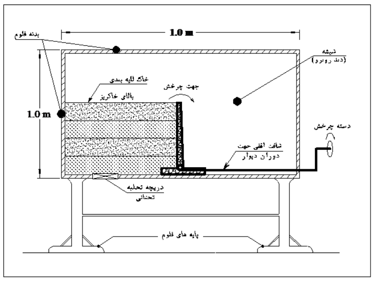

Figure 1. Cross section of the laboratory model

Since the main focus of this research is on investigation of the fracture wedge caused by wall rotational displacement, the wall is fixed at toe using a shaft to prevent longitudinal displacement of toe so that the wall can only have rotational displacements. A handle was placed on the model which enabled us to rotate wall slowly by moving the handle.

Modeling layered embankments, 4 models were tested as follows:

- upper layer: Clay, bottom layer: sand
- upper layer: sand, bottom layer: clay
- upper layer: sand, middle layer: clay, bottom layer: sand
- upper layer: clay, first middle layer: sand, second middle layer: clay, bottom layer: sand

Vertical layers of soil were created slowly by pouring soils in thin layers to prevent its compaction. This method was adopted for all layers and thus, soil layers were formed at determined equal thicknesses. Figure 2 provides an example of soils layering behind the wall.

After each test the geometry characteristics of wedge consists of the angle of fracture with horizontal bed, height and length of wedge were measured. Then, the lateral pressure on wall were calculated using experimental measurements and the Elasto-plastic method and were compared to results of theoretical relations including Rankin and Sirinivasa methods.

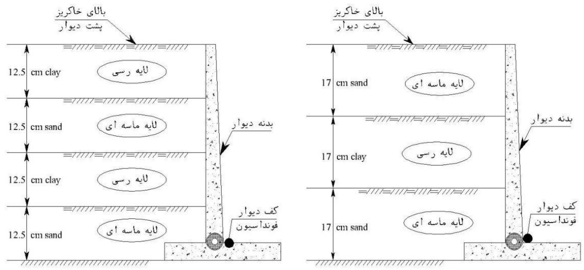

Figure 2. Details of soil layering behind the wall

3- Results and Discussion

Table 1 presents the failure angle of models in all of performed experiments.

Table1. Failure angle of tested models

No. of layers	Order of layers	Unsaturated	Saturated
4	clay	73	0
	sand	46	0
	clay	74	0
	sand	0	0
2	sand	64	56
	clay	77	59
3	sand	66	42
	clay	77	48
	sand	0	0
2	clay	78	0
	sand	53	0

Considering Table 1, it is inferred that in saturated conditions, the failure angle of the wedge would be reduced due to the act of adhesion force of soils. For example, the average failure angle for the three layered soil in saturated condition has reduced about 58.8% in comparison with unsaturated soil.

It must be noted that in unsaturated condition where the middle layer is made from clay, it has depreciated the failure wedge and reduced its dimensions due to the adoption of plastic deformation. Figure 3 presents the variations of the failure wedge in various layering conditions. Figure 3-a shows that in layering systems which the content of the clay is equal, the situation of the failure wedges are approximately similar. In addition, in saturated conditions, the content of development in the dimensions of the failure wedge increases as the quantity of clay in unit volume of soil samples increases (see Figure 3-b)

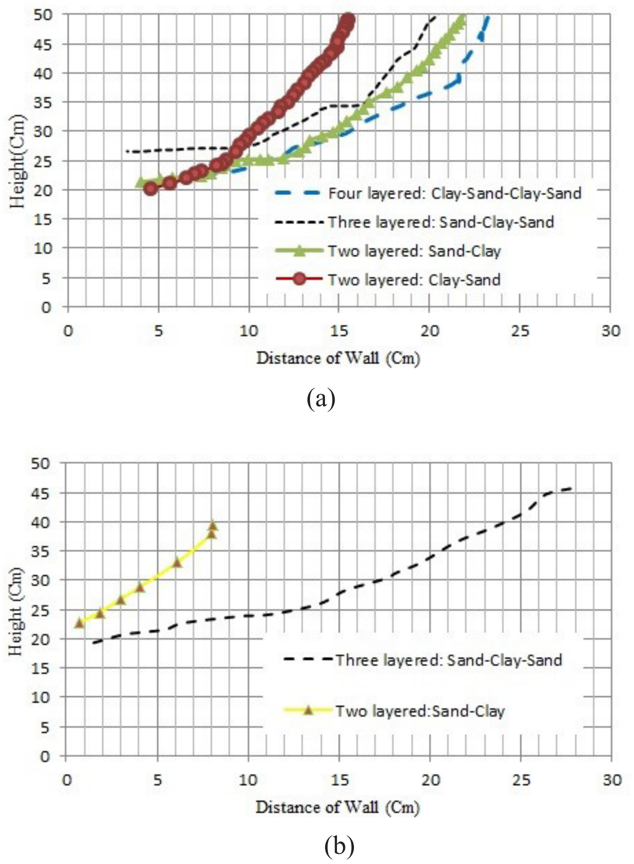

Figure 3. Comparison of failure wedge in various soil layering for a) Unsaturated and b) Saturated conditions

Experimental results obtained from laboratory tests of this research are compared to the results of common theoretical design methods in order to validate the results.

Table 2 compares the calculated values of lateral pressure obtained from experiments to some theoretical methods for all investigated models. It is obvious that the experimental results are significantly lower than calculated values from theoretical methods of Rankin and Sirnivasa. Hence, it could be inferred that, designing walls using theoretical methods, presents a conservatively design which increases the costs and the time of construction. There is a 16, 36, 45 and 30% difference between experimental results and the theoretical results presented in Table 2 in unsaturated condition for various soil samples in the order presented in the table.

It must be noted that, the difference between theoretical results and experimental ones is a result of simplifying assumptions apply in theoretical methods.

4- Conclusions

Magnitude of lateral forces are affected simultaneously by two factors of angle and the height of the failure wedge so that in a two layered soil sample with upper sandy layer, despite constant height of failure wedge, the angle of failure wedge in saturated layers has reduced by 18% in comparison with unsaturated layers and the lateral force reduced by 30%. Also, the 27% increase in lateral forces in three-layered saturated soils in comparison with unsaturated soils is caused by the average 37% reduction of the failure wedge angle despite its 30% increase of the failure wedge height in comparison with unsaturated conditions. Hence, In accordance with previous researches, status of the lateral pressure on wall could be estimated using the geometrical dimensions of the failure wedge.

Saturated homogenous soil puts higher active pressure on walls in comparison with unsaturated soils which consequently increases the active torque and leads to decrease in the safety factor of design. This is not necessarily true in layered soils so that in a two layered soil of (sand-clay), a smaller failure wedge in saturated condition, suggests a smaller active force and active torque in saturated in comparison with unsaturated condition.

Table 2. Comparison of calculated lateral forces with various methods

Layering	Rankin method (N/m)		Sirnivasa method (N/m)		Lateral pressure (N/m)	
	Unsaturated	Saturated	Unsaturated	Saturated	Unsaturated	Saturated
Two layer: Clay-Sand	0.61	0.51	0.56	0	0.48	0
Two layered: Sand-Clay	0.58	0.5	0.56	0.58	0.41	0.29
Three layered	0.68	0.62	0.64	0.93	0.44	0.56
Four layered	0.72	0.48	0.6	0	0.46	0

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