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Displacement Based Analysis of Retaining Wall with Narrow Backfill under Rotation about Bottom Mode

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Abstract. The narrow-backfill walls are common geotechnical structures that are constructed in hilly terrains for building up the pavements. Rankine's method or Coulomb's earth pressure theory over-estimates the lateral earth pressure acting on the narrow backfill walls resulting in an uneconomical design. The paper presents the behavior of the wall retaining a backfill with narrow width under rotation about the bottom mode of wall movement. The Finite element approach is adopted to address the present problem. The results obtained from the model are compared with an existing centrifuge model test to validate the model. The earth pressure distribution on the retaining wall for different widths of the backfill is presented. The reduction in the earth pressure coefficient with respect to Coulomb's coefficient for different widths of the backfill is reported. The failure planes for different widths of the backfill are obtained from the strain contours. These failure planes suggest that as the width of the backfill reduces, the soil mass participating in the failure reduces, resulting in the reduction in lateral earth pressure acting on the wall.

Keywords: Critical failure plane; Earth pressure; Finite element model; Narrow backfill; Retaining wall.

1 Introduction

Retaining walls are the most common geotechnical structures used in any nation's highway construction. The earth pressure distribution is generally an important factor for estimating point of application of lateral thrust. Though distribution is assumed as linear, many studies have revealed that the realistic distribution is non-linear and mostly curvilinear ([1], [2], [3], [4]). The construction of retaining wall involves many complications in practical view point. One of the complication is construction of retaining wall in hilly areas where the space of the backfill is constrained [5]. Considering construction methodology of such retaining wall as out of scope, the present paper emphasizes on the analysis. In general retaining walls are analyzed using conventional earth pressure theories namely Coulomb's earth pressure theory or Rankine'

theory yields a poor design of retaining wall in economy grounds. [6] is pioneering study that addressed the effect of confinement of backfill material in silos aspect. The earth pressure acting on the retaining wall is majorly affected by arching affect in the backfill ([7], [8], [9], [10]). This effect is phenomenal in the case of retaining walls with narrow backfill. Researchers in the previous study have addressed the problem in three different approaches namely experimental, analytical and numerical approach.
[11] adopted limit equilibrium to analyse retaining wall with reinforced backfill in limited space. This study proposes design charts to obtain lateral earth pressure for different height to width ratio of backfill. [12, 13] also proposed analytical solution for retaining wall with narrow backfill width. [13] has divided the problem into different mechanisms based on the width of the backfill. The study reveals that as width of the backfill reduces the number of potential failure wedges increases. As width reduces the induced failure plane coincides with the lateral constraint and affects the weight of the soil participating in the failure. As the weight of the soil participating in failure plays an important role in attaining limit equilibrium, it affects lateral pressure acting on the wall.

The available literature has number of studies in analytical approach, there are very limited number of papers that offer experimental view to study the problem. [14] conducted laboratorial test to study the effect of backfill width on lateral earth pressure acting on the retaining. The study presents centrifugal tests for different widths of the backfill. The study reveals that arching effect in backfill due to lateral confinement plays an important role in reduction in lateral earth pressure acting on the retaining wall. Confinement of backfill is mainly due to rigid retaining wall on one side and lateral constraint like hillock on other side. A virtual arch is formed in the backfill starting from vertical wall and ending on the other side i.e. on hillock side. The total vertical overburden pressure acting in the soil is reacted by this virtual arch and the friction between backfill and retaining wall, backfill and hillock on the other side. Thereby reducing net vertical pressure in backfill, further reducing the lateral earth pressure acting on the retaining wall. [15] had conducted centrifugal test to study the effect of arching in reduction in lateral earth pressure in the case of narrow backfill. This study considered an at-rest condition to know behavior of un-yielding retaining wall. Very recently, [16] conducted laboratorial study to know the behavior of narrow backfill wall for three different modes of yielding of retaining wall namely sliding mode, rotation about bottom and rotation about top. The study reveals that the measured earth pressure coefficient is much smaller than compared to Coulomb's earth pressure coefficient.

Apart from experimental investigation, numerical analysis also gained enough recognition in the literature. Though the experimental study provide a detailed behavior of retaining wall, the study can only be done to a model. Whereas, in numerical approach has its own advantage of studying for any scale of the problem. Each approach have its own advantages. [17, 18] proposed numerical analysis to study the effect of width of the backfill.

The present study considers a narrow backfill retaining wall in a numerical background using PLAXIS-2D software. The study examines the effect of width of the backfill on lateral earth pressure acting on the wall. The type of displacement in the wall adopted in the study is rotation about bottom. The effect of backfill width on the induced potential failure plane is presented. Further, the study presents the influence of aspect ratio of backfill space on the coefficient of lateral earth pressure coefficient.

2 Methodology

The present numerical analysis by varying width of the backfill is carried in PLAXIS-2D software. The present problem deals with retaining wall, the strains in length direction are assumed to be zero. Hence to reduce computational effort the present problem is assumed to obey plane strain condition.

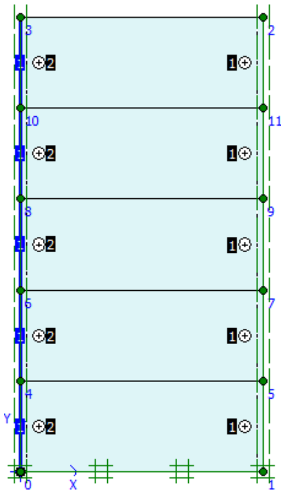

Fig. 1 Finite element model adopted for the study.

Fig. 1 shows the model of retaining wall used in the study. The model is analyzed accordingly by varying width of the backfill. The present model has an element with 15 nodal points. This consideration improves the accuracy in the results obtained.

Table 1 Properties used in the numerical analysis

Material	Property	Value
	Unit weight	13.4 kN/m^3
Soil	Friction angle	29º
	Model	Mohr-Coulomb
	Normal Stiffness	1.26E7kN/m
Wall	Flexural stiffness	4.2E4kN-m^2/m
	Model	Plate-Linear elastic

In the present study the height of the wall is fixed as 5m and the width of the back-fill is varied. Mohr-Coulomb failure criterion is adopted for modelling backfill soil. Table 1 shows the different properties considered in the model. Horizontally fixed vertical boundaries are adopted in the study to allow vertical displacement. Whereas horizontally and vertically fixed, bottom horizontal boundaries are adopted in the model. It is recommendable that a reduced value of the shear strength is to be considered at the interface of the wall-backfill. Therefore, separate interface elements are modelled. Staged construction is adopted to simulate the field conditions in the model.

To conduct a detailed study, the adopted model is validated with an experimental study. For this objective, the model is compared with that of [15] maintaining the same geometrical limitations. [15] performed a centrifugal test to evaluate lateral earth pressure acting on an unyielding wall. The test considers a wall height of 5 m with four different widths of the backfill (6.57m, 2.67m, 1.36m and 0.56m). Fig. 2 shows the finite element mesh generated in numerical analysis. The soil properties adopted in the analysis are considered from [15]. The lateral earth pressure distribution on the wall is considered as the parameter to validate the present finite element model.

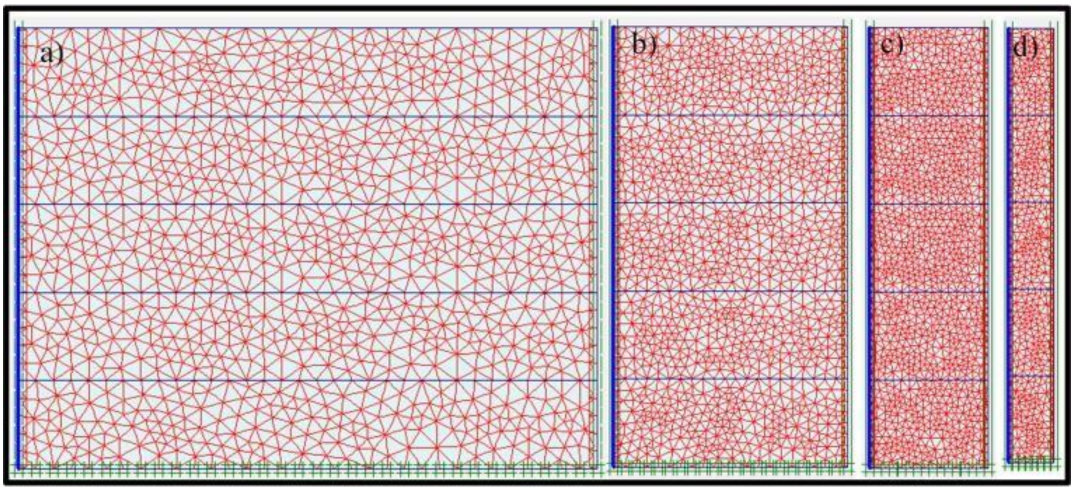

Fig. 2. Finite element mesh generated for four different widths of backfill a) 6.57m, b). 2.67, c). 1.36m, d). 0.56m

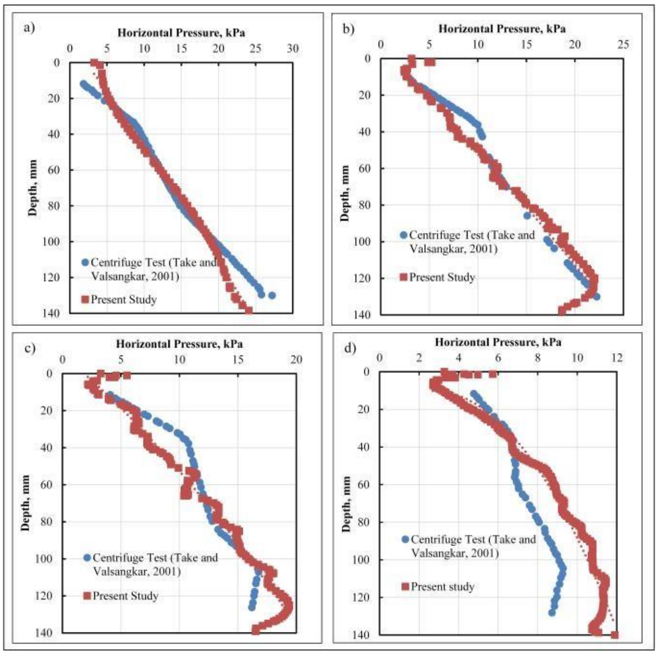

Fig. 3. Earth pressure distribution acting on the retaining wall with different backfill widths a) 6.57m, b) 2.67m, c) 1.36m and d) 0.56m

Fig. 3 shows the earth pressure distribution acting on the unyielding wall obtained from centrifugal test and numerical analysis for the four considered widths of the backfill.

3 Results and Discussion

Numerical analysis is conducted for the wall rotating about bottom mode. To simulate the rotation about bottom mode, the wall is prescribed with varying displacement. In particular, zero displacement is prescribed at bottom of the wall and a maximum displacement of 20mm (0.4% of height of the wall) is prescribed at top of the wall as shown in Fig. 4. The displacements in the model is activated after activating the wall elements and soil cluster in construction stage.

Fig. 5 shows the maximum shear strain contours which are considered as failure planes in the present study. The potential failure angle is observed to be around 56.4^{o} with respect to horizontal plane. Fig. 6 shows the variation of normalized coefficient of lateral earth pressure coefficient with respect to aspect ratio of backfill space (width/height). The normalization of coefficient of lateral pressure is done by considering the ratio of obtained coefficient of earth pressure from numerical analysis to the coefficient of earth pressure obtained from Coulomb's theory ($K_{a(FEM)}/K_{a(Coulomb)}$) as shown in the Fig. 6.

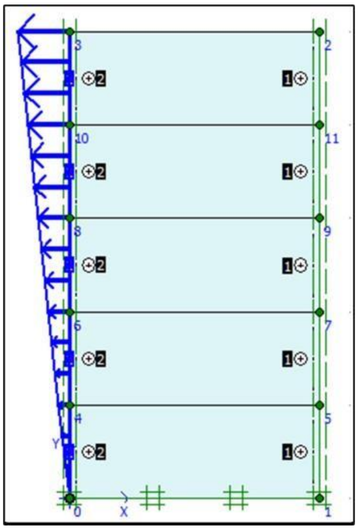

Fig. 4 . Geometrical model showing rotation of wall about bottom

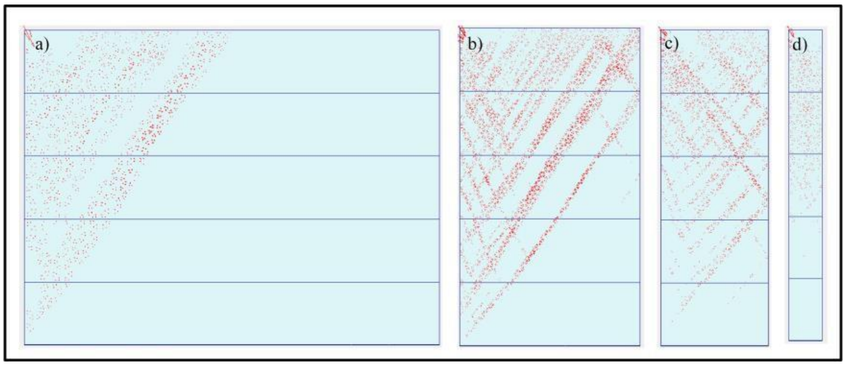

Fig.5. The Failure planes obtained for different depths of backfill a) 6.57m, b) 2.67m, c) 1.36m and d) 0.56m

It is observed from Fig. 6 that as aspect ratio of backfill space decreases the coefficient of lateral earth pressure reduces. Though small discrepancy is observed at an aspect ratio of 0.3, the value of coefficient reduces. From the Fig. 6 it is evident that the lateral earth pressure ratio ($K_{a(FEM)}/K_{a(Coulomb)}$) remains unity for the aspect ratio greater than unity.

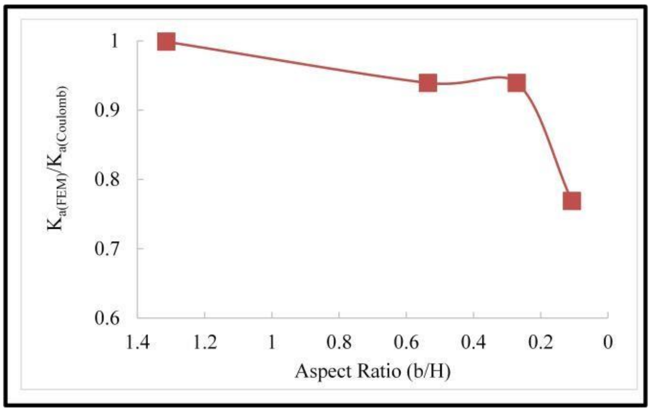

Fig. 6. Variation of lateral earth pressure coefficient with aspect ratio of backfillspace.

4 Conclusions

The proposed study considers displacement based numerical approach to investi- gate the effect of aspect ratio of backfill space on lateral earth pressure coefficient. The rotation about bottom mode is adopted and the pressure acting on the wall due to backfill soil is estimated. Firstly, the adopted model that used for the study is validat- ed by comparing lateral earth pressure obtained from a laboratorial centrifuge test adopted from the literature. The comparison of lateral earth pressure obtained from numerical study and centrifugal study are observed to be in good agreement. The rotation in the wall is applied about bottom. The lateral earth pressure obtained for different widths is estimated. The failure plan for each widths of the back fill is pre- sented in the study. It is observed that the failure plane is contained in the backfill as the aspect ratio of the backfill space is reduced. The reduction in the lateral earth pressure as the aspect ratio of backfill space is reported in terms of coefficient of lat- eral earth pressure ratio.

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