Analysis of retaining wall with constrained backfill for sliding mode of wall movement

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ABSTRACT

Retaining wall built in front of a stable rock face or an existing wall retains limited width of backfill. Conventional earth pressure theories are not applicable in analysis and design of such retaining structures. The purpose of the study is to investigate the effect of wall movement on the earth pressure acting on the retaining wall with narrow backfill width. The effect of sliding mode of wall movement on lateral earth pressure for different backfill widths using finite element analysis is presented. After the proximate validation of model with existing centrifuge test, the analysis yields that lateral earth pressure acting on the wall is remarkably reduced with reduction in aspect ratio of backfill width. The rationale for reduction is observed to be objection of failure plane because of constraint. The present study definitively answers questions regarding effect of containment of backfill in the context of sliding mode of wall movement.

Keywords: Aspect ratio; constrained backfill; earth pressure; finite element analysis; sliding.

1 INTRODUCTION

If a retaining wall is constructed in front of an intact rock or a stable wall then the backfill width provided will be much less than a conventional retaining wall. In these circumstances, applying conventional earth pressures theories result in over-estimation of earth pressure further affecting economy of the project. Spangler and Handy (1984) suggested Janssen's arching theory (1895) to estimate lateral earth pressure for constrained backfill. Janssen's theory was used to estimate Silo pressure. Spangler and Handy (1984) did not discuss about the choice of the value of coefficient of earth pressure to be used in the calculation. Janssen's theory was used to estimate Silo pressure. Frydman and Keissar (1987) conducted a Centrifugal model test for the problem of constrained backfill in at-rest and active conditions. For estimation of active earth pressure reduced $\emptyset$ is used which is due to progressive failure of soil mass. Frydman and Keissar (1987) did not discuss about scattering of earth pressure on wall as they have used only two pressure cells in the experimental setup. Take and Valsangkar (2001) performed a series of centrifuge tests using number of pressure cells in both vertical and lateral directions. To overcome the drawback of previous study, authors had come up with variation of earth pressure with depth. The study also describes about the effect of stiffness of pressure cells on measured lateral stress. Leshchinsky et al. (2003) analyzed a reinforced earth wall with narrow backfill with an assumption that all the reinforcement layers are replaced by an equivalent reinforcement layer at a height of one third of height of the retaining wall to enable development of non-dimensional design charts. This assumption also enables in extending the analysis for estimation of lateral earth pressure coefficient for a gravity retaining wall. Design charts are developed to estimate coefficient of earth pressure for narrow backfill which requires bottom width, angle of rock slope as input parameters. Authors have performed both limit equilibrium analysis and Finite difference analysis. Yang and Liu (2007) for the first time modelled problem to perform finite element analysis. Authors have showed the variation of coefficient of earth pressure for at-rest case and active case with depth at face of the wall and at mid width of backfill for different aspect ratio. Results obtained from the study are compared with Janssen's arching theory and Leshchinsky (2003). Important contribution of the work is authors have developed design charts for reduction factors to estimate at-rest and active pressures for narrow backfill retaining walls. Reduction factor can be used in combination with FHWA design charts. Fan and Fang (2010) performed numerical analysis using finite element modelling for varying width of the backfill. Nandukuru and Michalowski (2012) modelled problem in discrete element modelling. Paper presents local equilibrium (horizontal slice) whereas in Coulomb's analysis global equilibrium was carried out. There by load distribution over height of the wall is presented which is not possible in the case of Coulomb's analysis as it is force equilibrium. Greco (2013) performed limit equilibrium analysis for the problem. Based on the width of the backfill, problem is divided into three mechanisms. Mechanism 1 is just similar to Coulomb's analysis with a single wedge. If backfill width is narrow enough to generate two failure wedges then it is categorized as Mechanism 2. Here author assumed that first wedge slides over the other. If three wedges are formed then it is categorized as Mechanism 3. With knowledge of Coulomb's theory Mechanism 1 can be solved. For Mechanism 2 Thrust wedges are described by cubic equation and Mechanism 3 thrust wedges are described by a cubic equation and the other quartic. Greco (2014) extended above mechanisms including seismic pseudo-static force in the Force equilibrium. Yang and Tang (2017) had conducted an experimental study for the problem for different modes of failure viz., Rotation about top, translation and Rotation about bottom. It is observed that test yields different coefficient of earth pressure values for different modes of failure and in contradictory to limit equilibrium analysis conducted by Greco (2013) failure plane observed to be non-linear.

2 NUMERICAL MODELLING AND VALIDATION

In the present study, PLAXIS code is developed to study the effect of wall movement on lateral earth pressure. Fig. 1 shows a typical PLAXIS model considered for the analysis. Assuming infinitesimal length of the wall-backfill, modelling considers plane strain condition. In respect to the accuracy, each element is modelled as 15 nodded. Width of the backfill is changed by fixing the height of the retaining wall to 5m. Backfill soil is assumed to obey Mohr-Coulomb failure criteria i.e., soil behaves as an Elasto-plastic in nature. Cohesion-less soil is assumed in the analysis with a unit weight of 16.2kN/m3. Angle of internal friction of the soil is assumed to be 36^{o}. In order to avoid numerical instability a small and negligible amount of cohesion is introduced in the soil. Soil is also assumed to obey non-associative flow rule by considering zero dilation. The Plate material is consider to simulate wall.

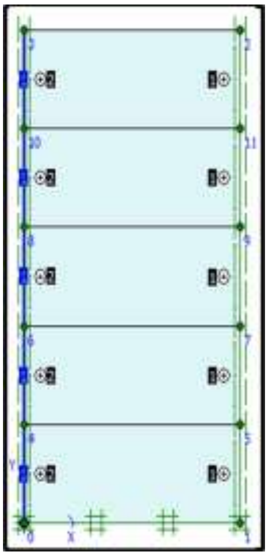

Fig. 1. Typical geometric model used in the analysis.

By considering rigid wall properties, bending and shear deformations are avoided in the wall while placing the layers of the soil. Normal Stiffness (EA) and flexural rigidity (EI) of the wall are 1.26 X 10^{7} kN/m and 4.2 X 10^{5} kN-m^{2}/m respectively. Vertical boundaries of the geometrical model are restrained in horizontal direction whereas bottom horizontal boundary is restrained in both horizontal and vertical directions. Separate interface elements are modelled to simulate interface between two boundaries. Interface elements enables to study the effect of interface friction angle on lateral earth pressure. To simulate field conditions backfill soil is filled in stages. Plastic analysis after stage construction is carried out to study the behavior to retaining wall. It is known fact that to create an active condition or passive condition in the backfill, the wall has to be displaced either away from the backfill or towards the backfill by 0.1 to 0.5 percent of wall height. Therefore failure criteria for different widths of backfill is presented by sliding mode of wall movement.

2.1 Validation of Methodology

Take (2001) Conducted retaining wall model test in a centrifuge setup. One of the major outcome of the test is the effect of width of the backfill on lateral earth pressure acting on an unyielding wall. Take's centrifuge test is considered to validate the present model. A full scale prototype retaining wall is modelled in PLAXIS. Take (2001) modelled a retaining wall of height of 140 mm, with four different widths of backfill (184 mm, 75 mm, 38 mm and 15 mm) and applied centrifuge action with an acceleration of 35.7g. That implies centrifuge model studied replicate a retaining wall of height 5 m. Finite element mesh generated for different widths of retaining wall is shown Figure 2.

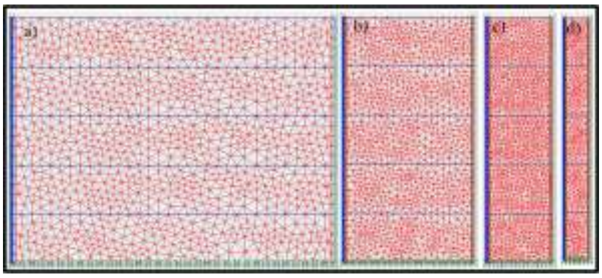

Fig. 2 Finite element mesh of retaining wall for widths a) 184mm b) 75mm c) 38mm d) 15mm.

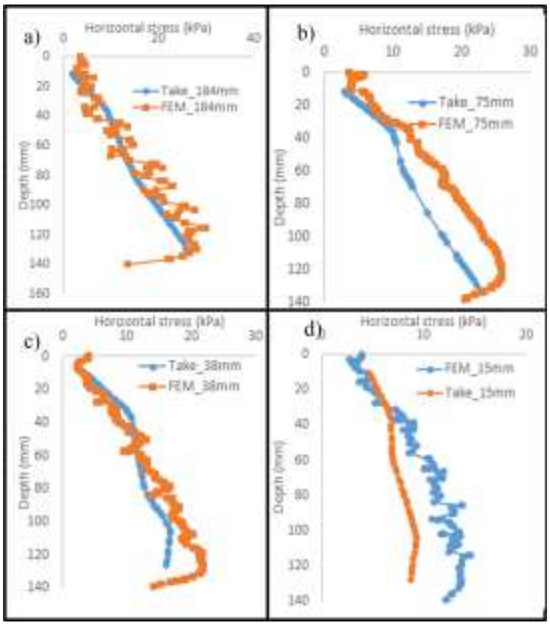

Fig 3. Validation of FE model by comparing horizontal pressure with centrifuge test (Take 2001).

With the same soil properties used by Take (2001), finite element analysis was conducted using plastic analysis. Present model is validated by comparing earth pressure distribution on retaining wall for different backfill widths. Figure 3 presents the lateral earth pressure acting on the wall for backfill widths of 6.568m, 2.67 m, 1.356 m, 0.535m which simulates model widths of 184 mm, 75 mm, 38 mm, 15 mm respectively. It is evident that the present model captures the effect of containment of the backfill soil. From the lateral earth pressure distributions for different backfill widths it is observed that as width of the backfill reduces, the total thrust acting on the wall reduces. The reduction in the lateral thrust is attributed to the reduction in net vertical pressure of the backfill in advent of increase in friction in interface elements. This phenomenon plays a vital role when the wall is subjected to movement as presented in the study.

2.2 Sliding mode of wall movement

The interface friction between soil and wall plays an important role on lateral earth pressure acting on the retaining wall for different modes of wall movement. To study the effect of wall movement, finite element analysis is conducted for sliding. In the sliding mode wall is made to move about 0.4% of the wall height which is equal to 20mm. Plastic analysis is conducted in different stages. In the first stage, retaining wall is activated which provides a lateral support to the backfill soil which is filled in five stages. After re-setting construction displacements to zero, wall is allowed to slide.

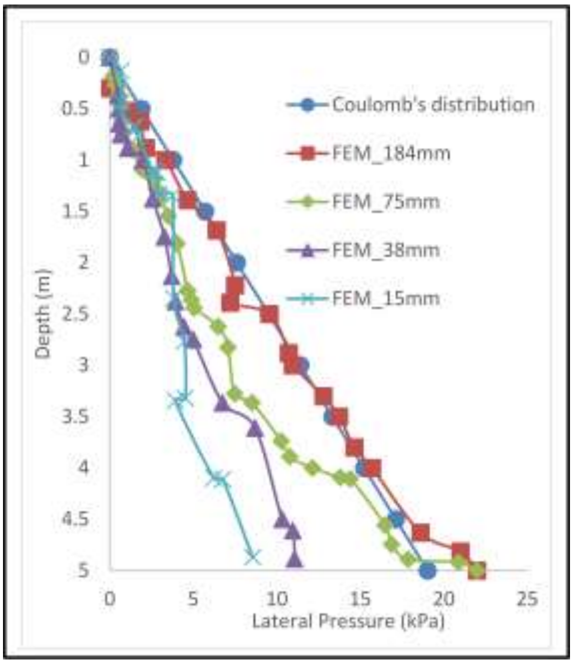

Fig 4. Earth pressure distribution for different widths of backfill and their comparison with Coulomb's distribution.

Figure 4 shows earth pressure distribution obtained from Coulomb's theory and finite element analysis for different widths of the backfill. It is evident that earth pressure distribution for 184mm width is almost same as coulomb's distribution. For widths 75mm, 38mm, 15mm though distribution patterns are observed to be similar but magnitudes are lesser compared to that of Coulomb's theory.

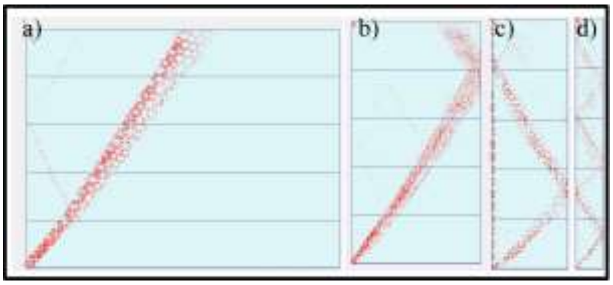

Fig. 5 Failure planes for different backfill widths a) 184mm b) 75mm c) 38mm d) 15mm.

Figure 5 shows failure planes generated for different widths of the backfill. For width 184mm, a full failure plane is developed till the backfill surface. But for width 75mm, 138mm, 15mm failure plane developed is multi-linear in nature based on the width. This result from the study is in agreement with the study proposed by Greco (2013). Figure 6 shows a plot between reduction in earth pressure coefficient and aspect ratio (width (b)/Height (H)) of the backfill. As the aspect ratio of backfill reduces the coefficient of lateral earth pressure reduces. For the different narrow backfill wall which could not produce a full length failure plane, following design curve can be used to estimate coefficient of lateral earth pressure.

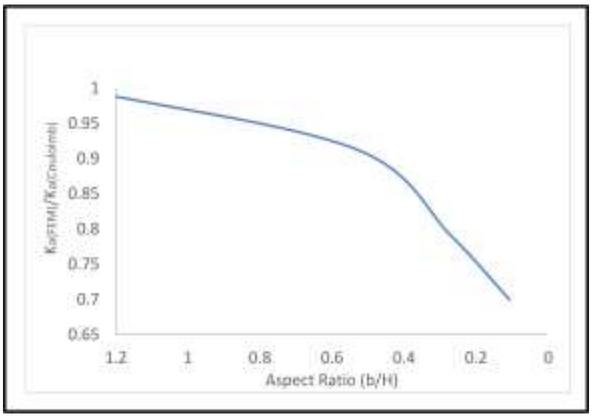

Fig. 6 Reduction in coefficient of earth pressure for different aspect ratios of backfill width.

3 CONCLUSION

The effect of backfill width on the lateral pressure acting on the wall is studied in finite element frame work. Firstly Model generated for the analysis is validated with available laboratorial study. It is observed that as width of the backfill reduces lateral earth pressure acting on the wall reduces. Failure planes generated for different aspect ratio suggest that multi linear failure planes are developed in the backfill based on its width. For a reduction in aspect ratio from 1.3 to 0.5, there is a reduction in lateral earth pressure of about 9% whereas for aspect ratios 0.2 and 0.1 the reduction in lateral earth pressure is remarkable of about 21% and 30%. Consideration of conventional earth pressure theory for analysis of retaining walls with constrained backfill yields uneconomical results. In that case proposed methodology can be employed based on the magnitude of the allowable wall movement.

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