REDUCTION OF SURCHARGE INDUCED EARTH PRESSURE ON RIGID NON-YIELDING RETAINING WALL USING RELIEF SHELVES

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ABSTRACT: Present study is conducted to investigate the effectiveness of relief shelf to reduce the lateral thrust on rigid non-yielding retaining wall, through a small scale physical model test in laboratory. The height of the model retaining wall was 700 mm, and 5 earth pressure sensors were used to measure the lateral pressures along the height of the retaining wall with and without relief shelves. A maximum surcharge pressure of 50 kPa was applied on the backfill. From the results of the study, it is found that relief shelves are effective in reducing total thrust on wall. A parametric study is also carried out on 8m high wall having 3 relief shelves by varying the width of shelves, through numerical analyses using FLAC^{3D}. The study reveals that relief shelves having width factor ranging 0.3-0.8 can reduce total thrust on the wall in range of 11-26%. Among all the cases of retaining wall with relief shelves analyzed in the present study, retaining walls with shelf width of 1.4m (width factor of 0.7) exhibited substantial reduction in lateral thrust, without leading to excessive deflection of relief shelves and backfill surface settlement.

KEYWORDS: lateral earth pressure, retaining wall, relief shelf, FLAC^{3D}

1 INTRODUCTION

Assessment of magnitude and distribution of lateral earth pressure on retaining wall under various loading conditions had been an important area of research for geotechnical engineers, as the total thrust on wall is the key factor to decide the sectional dimensions of retaining wall. By reducing the lateral earth pressure on wall, sectional dimensions of wall can be significantly reduced, which would lead to overall economy in construction of retaining wall. Among various measures to reduce total thrust on wall, such as use of expanded polystyrene (EPS) geofoam, geo-boards, rubber tyre chips etc., construction of retaining walls with relief shelves is the least explored technique. However, many retaining walls have been constructed with relief shelves in countries like India, China and Korea (Chauhan *et al.* 2016). A similar study was also conducted to understand the possible reasons behind the failure of a cantilever retaining wall with relief shelves, which is located in the heart of Hyderabad city, India (Chauhan *et al.* 2016). Although such type of walls have already been constructed for more than a decade, the mechanism behind the reduction of lateral pressures and design parameter estimation are still in immature state. Hence, present study is aimed to understand the behaviour of such walls and to evaluate the effectiveness of relief shelves in lateral earth pressure reduction. Rigid non-yielding retaining walls with and without relief shelves are considered in the present study and modelled through small-scale physical model tests and full scale numerical model study.

2 PHYSICAL MODEL TESTS

To evaluate the effectiveness of relief shelf, small-scale physical model tests are carried out with and without relief shelves with various combinations of location and width of relief shelves. To study the influence of relief shelf on lateral earth pressure distribution on an at-rest wall, 1-g small scale physical model tests are carried out in a stainless steel tank having dimensions of 1.2m length, 0.31m width and 0.7m depth. Details of the experimental setup are shown in Figure 1. Six diaphragm type earth pressure cells (EPCs) are fixed along the height of model retaining wall to get the lateral earth pressure distribution on wall. A mechanized travelling pluviator (Gade and Dasaka, 2016) is used to prepare uniform sand bed of 80% relative density (friction angle 39° and bulk unit weight 16.5 kN/m^3), while maintaining a height of fall 0.3 m. A uniformly distributed static loading of maximum 50 kPa in 10 kPa increments is applied on the surface of backfill using a hydraulic actuator, and the corresponding load distribution system is shown in Figure 1. The set up facilitates uniform application of surcharge on the backfill.

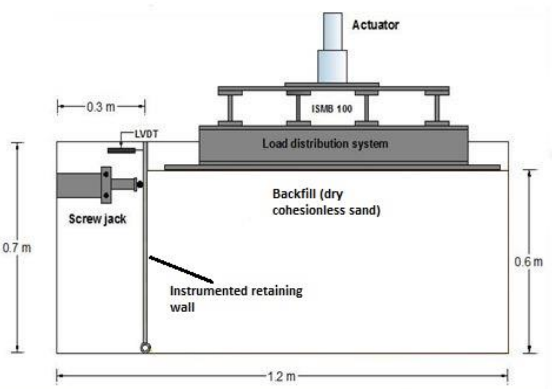

Fig. 1 Detailed experimental setup used in model tests

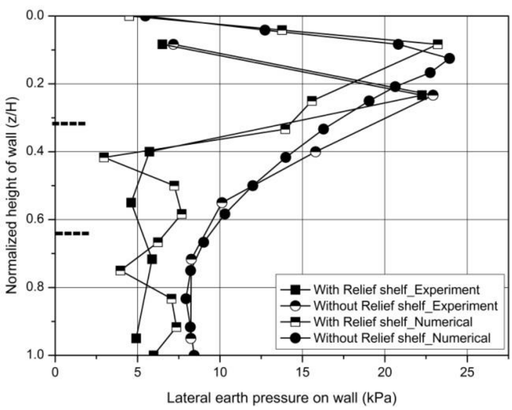

Fig. 2 Comparison of physical model and numerical analysis with and without relief shelves

Figure 2 shows the experimental findings of lateral earth pressure distribution on 0.6 high wall with 2 relief shelves (width 10 cm each placed at z/H= 0.33 and 0.66) and static surcharge of 50 kPa. The earth pressure variation on walls with without relief shelves is also shown in the figure. From the results, it is noted that lateral earth pressure below the relief shelves gets reduced substantially.

3 MODELING OF RETAINING WALL WITH RELIEF SHELVES

To evaluate the influence of relief shelf location and width, numerical simulations are carried out with a 8 m high wall (H), having 3 relief shelves of same widths and located at different position factors, α (z/H= 0.27, 0.56 and 0.84) along the wall. The thickness of relief shelves is kept constant at 0.3 m. Figure 3 shows the numerical model used in the present study.

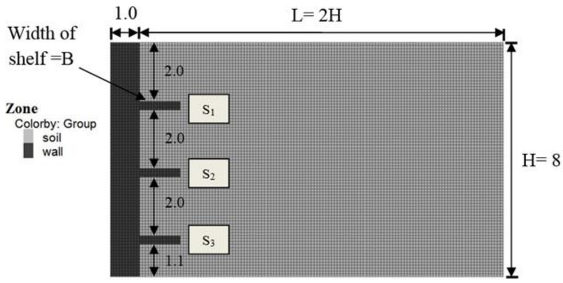

Fig. 3 Numerical model of rigid retaining wall with relief shelves, all dimensions in m (not to scale)

Physical properties and chosen model for the backfill (dry cohesionless soil) and retaining wall are selected from a similar study on retaining wall with relief shelves (Chauhan *et. al.* 2016). In the present study, width factor, β, of relief shelf is varied from 0.3-0.8, to examine the distribution of lateral earth pressure at various sections of wall and total thrust reduction, where β is defined as ratio of B/h (B is width of relief shelf and h represents intermediate height of section of wall between two consecutive relief shelves, which is considered as 2 m in the present study). With this convention of notation, conventional retaining wall without relief shelves is referred to as the wall with β equal to zero. Fixed boundary condition at bottom of the model and roller boundary condition at vertical end of soils are chosen to simulate the field conditions of rigid retaining wall-backfill system. Length of retaining wall (across the plane) is considered as 1.0 m in the present analyses. The rigid wall is modelled as elastic material and not allowed to move away from its initial position to simulate non-yielding condition (at-rest) of wall. The interface between wall and soil is modelled as linear spring-slider system with interface shear strength defined by the Mohr-Coulomb failure criterion (FLAC^{3D} 2011). Once the model reaches equilibrium condition, a static surcharge of 50kPa is applied in the form of strip loading on the backfill surface starting at 0.4 m (H/20) away from the edge of wall. The numerical model used in the present study is validated using lateral earth pressure profiles obtained from experimental studies on wall with two relief shelves and without relief shelf, as presented in Figure 2.

4 RESULTS AND DISCUSSION

In the present study, rigid retaining walls with three relief shelves positioned at α = 0.27, 0.56 and 0.84, and β in the range of 0.3-0.8 are analysed with FLAC^{3D}, to evaluate the influence of β on lateral earth pressure distribution, total lateral thrust, backfill settlement and deflection of relief shelves.

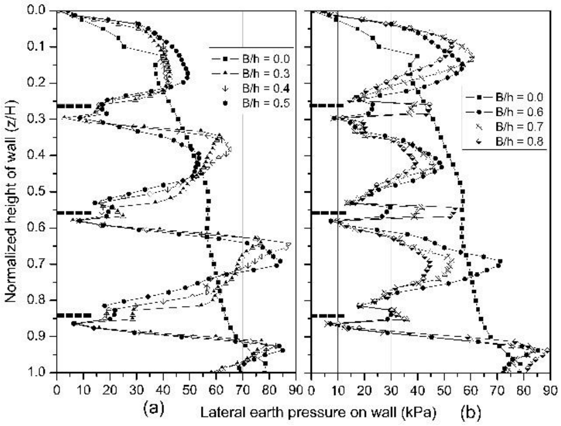

Fig. 4 (a) and (b) Comparison of lateral earth pressure on the wall with and without relief shelves

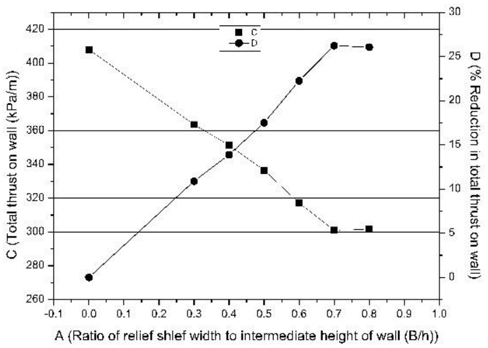

Fig. 5 Total thrust and reduction in thrust on retaining walls

Earth pressure distribution on all walls with and without relief shelves are studied and shown in Figure 4. It can be observed that lateral earth pressure in topmost segment of wall increases with the increase in width factor of relief shelf. This behaviour may be attributed to the fraction of applied surcharge load carried by topmost relief shelf. As the width of relief shelf increases, a greater portion of surcharge is carried by the topmost relief shelf itself. Once loading on relief shelf increases, vertical pressure in the soil overlying a relief shelf also increases, leading to increase in the lateral earth pressure on wall. However, in lower sections of wall, lateral earth pressure has reduced significantly below the relief shelf (Figure 4a) compared to wall without relief shelf for β>0.5.

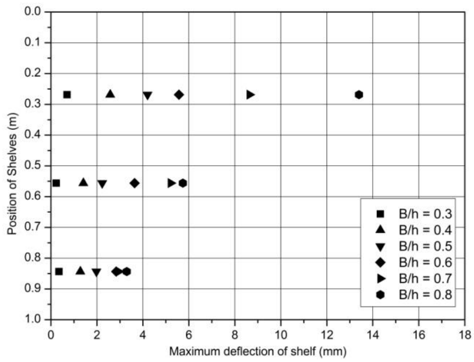

Fig. 6 Maximum vertical deflection (mm) profile of relief shelves

This behaviour of lateral earth pressure profile may be attributed to the surcharge above the relief shelf is being carried by relief shelves itself, and soil overburden and static surcharge is not getting transferred to the soil below the relief shelf, unlike in the case of wall without relief shelf. It is noted that when β≥0.6, significant reduction in lateral earth pressure is observed in the sections of wall lying between any two relief shelves (Figure 4b). A substantial reduction of lateral thrust, in the range of 11-26%, is noticed by provision of relief shelves of various widths, as shown in Figure 5. Although, for the relief shelves having β=0.3-0.5, a reduction of lateral thrust in the range of 11-17% is observed, this reduction is very significant for walls with 0.6≤β≥0.7. With further increase in β, no further increase in reduction of lateral thrust is noted. Maximum deflection of all relief shelves from top to bottom (S_1, S_2 and S_3) are compared and summarized in Figure 6. For a given wall, maximum deflection of relief shelf is found maximum for topmost relief shelf and it decreases from top to bottom relief shelves for all retaining walls. Maximum deflection of relief shelves has immensely increased when β>0.7. This behaviour may be attributed to greater part of applied surcharge is being supported by higher width of relief shelf and thickness of such relief shelves (0.3m) is not significant to support that much of surcharge. Surface settlement of backfill is an important serviceability criterion for retaining walls. Excessive backfill settlement leads to collapse of backfill soil and leads to failure of structures founding on it or in the close proximity.

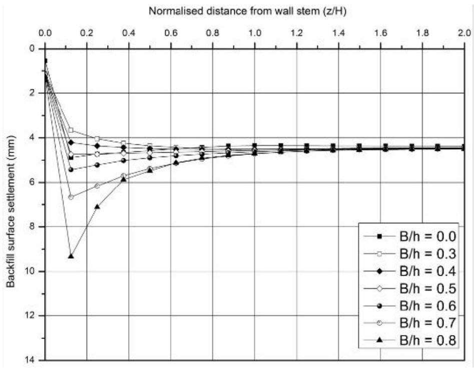

Fig. 7 Backfill Surface settlement profile of backfill

Backfill settlement near the wall is small (1-5mm) and it increases for walls with β>0.5, compared to wall without relief shelf (Figure 7). Although, with the provision of relief shelf, backfill settlement has reduced near the wall stem compared to wall without relief shelf (β≤0.5), but for walls having wider relief shelves (β>0.5), surface settlement near the wall is higher compared to that of wall without relief shelf. As discussed earlier, with increase in width of relief shelf, deflection of relief shelf increases, which leads to higher backfill settlement near the wall. When β>0.7, rapid increase in backfill surface settlement is observed near the wall stem, which is due to the higher deflection of relief shelf. Effect of provision of relief shelves on backfill surface settlement has continuously been diminished with increasing distance from stem and achieved the same profile, as that of walls without relief shelves beyond z/H ≥1. Among all the cases of retaining wall with relief shelves analysed in the present study, wall with β=0.7 provides maximum benefit in terms of reduction in total thrust, without leading to excessive deflection of relief shelves and backfill surface settlement. Maximum width of relief shelf should be restricted, as relief shelves having higher width experience large deflection leading to higher backfill surface settlement, which may affect the serviceability of nearby structures. Although, it is noteworthy that with increase in width of relief shelf, reduction in total thrust also increases but for a given height of wall and surcharge loading, there exists a certain upper value for width of relief shelf, which provides maximum reduction of total thrust on wall while satisfying the criteria for serviceability within limits. This maximum value of width of relief shelf depends on factors like height of wall, number of shelves and thickness of relief shelves, magnitude of surcharge loading and position of surcharge loading from face of the stem, etc. So, it is customary to examine aforementioned factors before deciding the number, position, width and thickness of relief shelf to be provided for any retaining wall, to achieve maximum benefit from the retaining walls with relief shelves.

5 CONCLUSIONS

Present study evaluates the effectiveness of rigid non-yielding retaining walls with relief shelves in reducing the lateral thrust acting on the wall. Small-scale physical model studies and numerical model studies on 8 m high retaining wall are carried out in the study. A surcharge load of 50 kPa on the backfill is considered in the study. Influence of width factor of relief shelf having 3 relief shelves of same width provided at different position factors, α=z/H, of 0.27, 0.56 and 0.84, is studied. The results obtained from the analyses revealed that provision of relief shelves on non-yielding rigid retaining wall provides significant reduction in total thrust on wall. For 8 m high retaining wall with three relief shelves, the reduction in lateral thrust is observed in the range of 11-26%. It is also noted that backfill surface settlement reduces due to relief shelves near the wall upto β=0.5. However, for walls with β>0.5, the backfill surface settlement increases with increase in width of relief. Also, it is observed that deflection of relief shelf is proportional to the width of relief shelf, and it also decreases from top shelf to bottom shelf for a given retaining wall with relief shelves. Among all the walls analyzed in the present study, retaining wall with 1.4m wide relief shelves (β=0.7) proves ideal, as it substantially reduces total lateral thrust, without leading to excessive deflection of relief shelves and backfill surface settlement.

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