Динамічна поведінка армованих підпорних стін

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У статті проаналізовано сейсмічну реакцію армованих підпорних стін з використанням методу кінцевих елементів. Досліджувалися зсуви стін різної висоти від 2 до 10 м, спричинені землетрусами. Проаналізовано різні співвідношення коефіцієнту довжини прольоту/висоти (L/H) й інтервалу армування. Для того, щоб з’ясувати відповідь армованих підпорних стін, які піддавалися дії землетрусу, проведено динамічний аналіз 20-секундного землетрусу в місті Адазапарі.

Вивчалися параметри довжини армування, прольоту, ваги і ширини блоку. Отримано наступні результати:

Підтверджено, як і очікувалося, що постійний зсув збільшується разом із зростанням висоти стіни.

Інтервал армування довжиною 0,2 м відносно 0,4 м суттєво скорочує зсув опорних стін під дією землетрусу. Цей наслідок показав, що 30% ширини блока дорівнює 20 см і 15% для Lw=40 см.

Збільшення коефіцієнта L/H з 0,7 до 1 немає ніякого істотного впливу на зменшення зсуву внаслідок дії землетрусу для елементів зі щільним армуванням.

Для інтервалу армування 0,4 м, вплив землетрусу на зсув може збільшитися на 2,5 %, при зменшенні коефіцієнта L/H з 1 до 0,7.

Зсув при збільшенні ширини блоку і довжини армування зменшується.

Блок шириною 0,2м відносно 0,4 м збільшує зсув на 29% при S=0,2м і γ=23кН/м3.

Блок шириною 0,2м відносно 0,4 м збільшує зсув на 44% при S=0,2м і γ=23кН/м3.

Незважаючи на збільшення ваги модульного блоку зсув підпорних стін збільшується.

Переклад виконано в Агенції перекладів PIO
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Dynamic Behavior of Reinforced Soil Retaining Structures

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In this study, a parametric study of seismic response analysis of reinforced soil retaining structures was performed using finite element analysis. The aim of the study is to determine the influence of reinforcement length, reinforcement spacing, wall height and facing block width and weight on seismic-induced permanent displacements. Permanent displacements under earthquake loading conditions associated with different L/H ratios and reinforcement spacing for different wall heights varying between 2 m to 10 m are investigated. 20 seconds of Sakarya earthquake was applied in dynamic analysis to understand the response of the reinforced soil retaining walls subjected to an earthquake.

Keywords: Finite Element Analysis, geosynthetics, reinforced soil, modular block, retaining wall

I. Introduction

This study deals with the calculation of permanent displacements of reinforced segmental retaining walls under earthquake loading condition. A commercial finite elements program “Plaxis” has been used to calculate the deformations.

Numerical simulations were carried out to investigate the influence of reinforcement stiffness, backfill material type and vertical spacing of the reinforcement on the seismic response of 2 - 10 m high reinforced soil retaining walls with modular block facing. The wall height, number of reinforcement layers and reinforced soil volume are typical of actual structures in the field

The Plaxis program which was used in the analysis of seismic response of reinforced soil walls, is a finite element package specifically intended for analysis of geotechnical engineering projects. In this finite element program a two-dimensional plain strain model is used for structures with a uniform cross-sections and corresponding stress-state and loading scheme over a certain length perpendicular to the cross section.

II. Modes of Failure

Stability analyses for geosynthetic reinforced segmental retaining wall systems under static and seismic loading conditions involve separate calculations to establish factors of safety against external, internal and facing modes of failure.

External stability calculations consider the reinforced soil zone and the facing column as a monolithic gravity structure. The evaluation of factors of safety against base sliding, overturning and foundation bearing capacity is similar to that used for conventional reinforced concrete gravity structures.

Internal stability analyses for geosynthetic reinforced soil walls are carried out to ensure that the structural integrity of the reinforced zone is preserved with respect to reinforcement over-stressing within the reinforced zone, pullout of geosynthetic reinforcement layers from the anchorage zone and internal sliding along reinforcement layers.

Facing stability analyses are carried out to ensure that the facing column is stable at all elevations above the toe of the wall and connections between the facing units and reinforcement layers are not over-stressed.

III. Sysmic Analysis of Approaches

Analytical and numerical approaches for the seismic analysis of reinforced walls can be divided into the following categories: Pseudo-static methods; displacement methods; and dynamic finite element/finite difference methods.

Pseudo-static methods extend conventional limit-equilibrium methods of analysis including destabilizing body forces that are related to assumed horizontal and vertical components of ground acceleration. As with all limit-equilibrium methods of analysis, pseudo-static approaches cannot explicitly include wall or slope deformations. This is an important shortcoming since failure of geosynthetic-reinforced soil walls, in particular, may be manifested as unacceptable movement without structural collapse. The permanent displacement of a geosynthetic-reinforced soil structure due to horizontal sliding/shear mechanisms can be estimated using one of the two general approaches

For a given input acceleration time history, Newmark's double integration method for a sliding mass can be used to calculate permanent displacement (Newmark, 1965). According to Newmark's theory, a potential sliding body is treated as a rigid-plastic monolithic mass under the action of seismic forces. Permanent displacement of the mass takes place whenever the seismic force induced on the body overcomes the available resistance along, a potential sliding/shear surface. Newmark's method requires that the critical acceleration, k_c, to initiate sliding or shear failure be determined for each translation failure mechanism. The value of k_c can be determined by searching for values of k_h that give a factor of safety of unity in pseudo-static factor of safety expressions. The critical acceleration is then applied to the horizontal ground acceleration record at the site and double integration is performed to calculate cumulative displacements.

IV. Modelling of Retaining Walls

Dynamic analysis of reinforced soil retaining walls subjected to the horizontal foundation shaking due to an earthquake was carried out using numerical models in 2m, 4m, 6m, 8m and 10m height walls with uniformly spaced reinforcement. The geometry of a typical wall is shown in Figure 1.

The changes were in the components and spacing of reinforcements inside the wall, not in the geometry of the model. For same geometry the properties of materials were changed in the analysis and the influence of the material properties (facing type, reinforcement stiffness, backfill type) were determined on the response of the walls to the seismic load in the Dynamic Module of the finite element program.

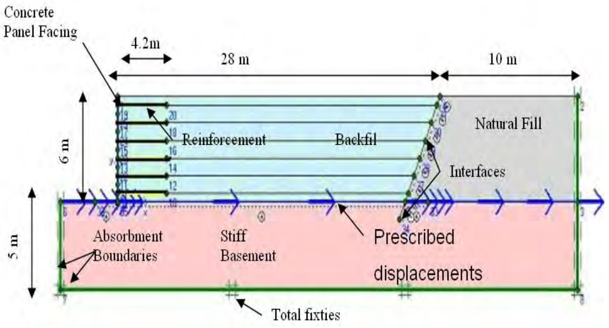

Figure 1. The geometry of model wall

4.1 Material Modeling

4.1.1 Modeling of the Soils

The Mohr-Coulomb model was used. This elastic perfectly plastic model requires five basic input parameters, namely Young Modulus (Elasticity Modulus) E, Poisson ratioν, cohesion c, internal friction angle ϕ, and dilatancy angle ψ.

4.1.2. Modeling of Reinforcement

The reinforcement layers were placed 0.2m and 0.4m in vertical spacing in different simulations to investigate the influence of vertical spacing on wall response. The width of L was selected for the reference geometry of reinforcement to give the ratio of L/H=0.7 where H is the height of the wall. This is the typical minimum reinforcement length over height ratio for static design of reinforced soil retaining walls. (Bathurst and Hatami, 1998)

4.1.3 Modular Block Facing Modeling:

The modular block facing elements are modeled as soil elements. Two block widths have been examined (0.2 m and 0.4 m). The block height was chosen as 0.2m for all cases. The unit weights of blocks were taken as γ_{block}=23 kN/m^3 and γ_{block}=13 kN/m^3 to represent full and hollow blocks respectively. Between two modular blocks, interface elements existed.

4.1.4 Modeling of Interfaces

Interfaces are used to model the interaction between structures and soil. The roughness of the interaction is modeled by choosing a suitable value for the strength reduction factor (R_{inter}) in the interface. This factor relates the interface strength (wall friction and adhesion) to the soil strength (friction and cohesion). The strength properties of interfaces are linked to the strength properties of soil layer;

$$c_{inter}=R_{inter} \times c_{soil} \quad (1)$$

$$\tan\phi_{inter} = R_{inter} \times \tan\phi_{inter} \quad 2)$$

In the current finite element model, between the base and the backfill soil and also between backfill and natural soil zone interface elements were used. Also between all block elements there were interface elements. The strength reduction factor was taken between backfill and base, backfill and natural soil, between modular blocks; 0.7, 0.5, 0.7 respectively.

4.2 Boundary Modeling

In the geometry of our model the right and the left boundary had horizontal fixity and the bottom boundary had total fixity which means a combination of both horizontal and vertical fixites ($u_y = 0$ and $u_x=0$).

In dynamic calculations absorbent boundaries were used. The absorbent boundaries are defined to take into account the fact that in reality soil is a semi infinite medium. So without these special boundary conditions the waves would be reflected from the model boundaries, returning into the model and disturbing the results. To avoid these spurious reflection absorbent boundaries were specified at the bottom right and left side boundary.

4.3 Mesh Generation

In order to perform finite element calculation, the geometry of the model has to be divided into elements. The generation process is based on a triangulation principle that search for optimized triangles and which results in an unstructured mesh. The numerical performance of these meshes is usually better than structured meshes with regular arrays of elements (Brinkgreve, R.B.J. and Vermeer, P.A., 1998).

The finite element mesh of current model is shown in Figure 2. Plaxis also gives opportunity to make refinement of mesh where the calculations must be more accurate.

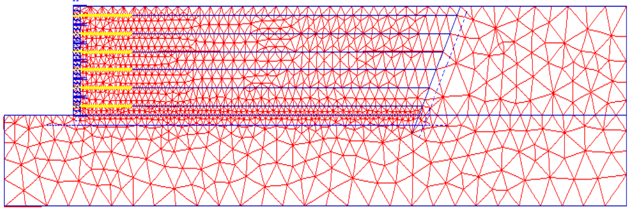

Figure 2. The finite element mesh of reinforced soil wall

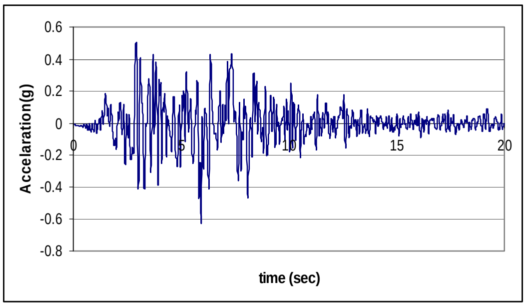

Figure 3. The acceleration time history of Sakarya Earthquake

4.4 Determining the Initial Conditions

After the geometry model and the finite element mesh have been generated, the initial stress state must be specified. The initial stresses in a soil body were characterized by an initial vertical stress σ_{vo} which is related by the coefficient of lateral earth pressure K_o where;

$$\sigma_{ho} = K_o \, \sigma_{vo} \quad (3)$$

V. Calculations

5.1. Dynamic Analysis

A numerical simulation of calculation was carried out on the reference wall model using the seismic data, Sakarya Earthquake, of which maximum acceleration and velocity are 0.628g and 0.277 m/s respectively. Its diagram is shown for duration of 20 seconds in figure 3.

VI. Results

From Figure 4 it can be seen that the displacement increases with increasing wall height. A vertical reinforcement spacing of S_v=0.2 m with respect to S_v=0.4 m reduces the permanent displacement by approximately 30% for a wall with L_w=0.2 m and γ_{block}=23kN/m^3. It is also observed that no significant change is observed between L/H=0.7 and L/H=1.

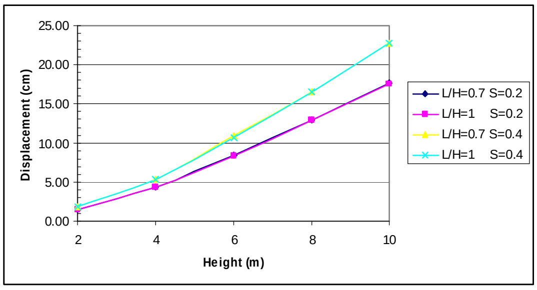

Figure 4. Total Displacement Change According to H, for S_v=0.2m and S_v=0.4m (L_w=0.2m; g_{block}=23kN/m^3)

A vertical reinforcement spacing of S_v=0.2m with respect to S_v=0.4m reduces the permanent displacement by 15% for a model with L_w=0.4m and γ_{block}=23 kN/m3 (Figure 5).

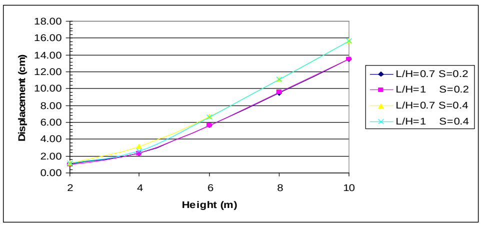

Figure 5. Total Displacement Change According to H, for S_v=0.2m and S_v=0.4m (L_w=0.4m; g_{block}=23kN/m^3)

A block width of L_w=0.2m with respect to L_w=0.4 m increase the permanent displacement by 29% when S_v=0.2m and γ_{block} =23kN/m^3 (Figure 6).

A block width of L_w=0.2m with respect to L_w=0.4 m increase the permanent displacement by 44% when S_v=0.4m and γ_{block} =23kN/m^3 (Figure 7). This indicates that the block width becomes more important for wider vertical reinforcement spacing.

From Figure 8 it can be seen that increasing the unit weight of facing blocks reduces the displacements of reinforced walls.

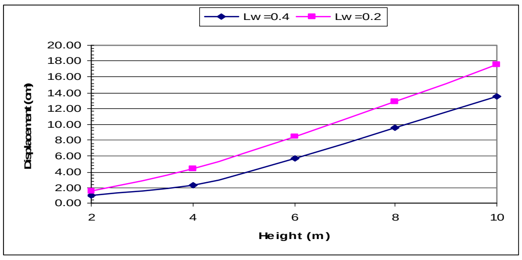

Figure 6. Total Displacement according to H, with L_w=0.2m and L_w=0.4m (L/H=0.7; S_v=0.2m; g_{block} = 23kN/m^3)

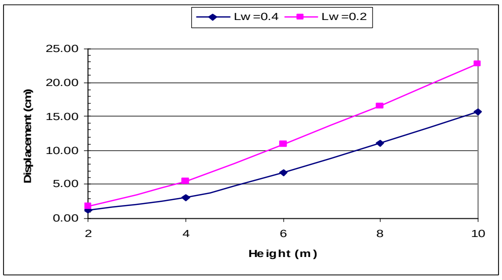

Figure 7. Total Displacement according to H, with Lw=0.2m and Lw=0.4m (L/H=0.7; Sv=0.4m; g_{block}=23kN/m3)

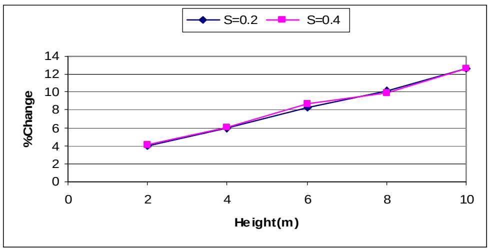

Figure 8. % Change of Displacement according to H, with “$_{block}$”13kN/m^3 and “$_{block}$”23kN/m^3 (L/H =0.7, L_w=0.2m)

Conclusion

The comparisons of the reinforcement length, reinforcement spacing, block unit weight, and block widths are studied. Following results were obtained.

As can be expected the permanent displacement increases with height of wall. The increase in block width and reinforcement length decreases the permanent displacement.

A spacing of 0.2m with respect to 0.4m reduces the permanent displacements under earthquake loading significantly. This reduction in displacement is 30% for block width of L_w=0.2m and 15% for L_w=0.4m.

Increasing L/H ratio from 0.7 to 1 has no significant effect on reducing the permanent displacements during earthquake loading condition for closely spaced reinforcement.

For reinforcement spacing of S_v=0.4m the permanent displacement under earthquake loading condition may increase as much as 2.5% when the L/H ratio is reduced from 1 to 0.7.

A block width of L_w=0.2m with respect to L_w=0.4m increase the permanent displacement by 29% when S_v=0.2m and by 44% when S_v=0.4m (γ_{block}=23kN/m^3). This indicates that the block width becomes more important for wider vertical reinforcement spacing.

Although increasing the unit weight of modular block increases the permanent displacement slightly, the effect is much more significant for higher walls.

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