Enhancement of Reinforced Soil Wall Performance under Dynamic Loading

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Certificate of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Dedicated to my ancestors

Abstract

Reinforced soils have been widely used in a variety of applications because of their satisfactory performance and cost effectiveness. A number of investigations to determine the seismic deformation modes of reinforced soil walls with conventional horizontal inclusions have already been conducted, but only limited investigations with the partial inclusion of vertical elements have been conducted, and then they did not consider the performance of reinforced soil walls under dynamic loading.

This research presents a new concept of soil reinforcement using vertical fortification designed to connect layers of conventional horizontal reinforcement together. For this proposed system, as with conventional reinforced soil, the selected granular material is compacted over the horizontal reinforcement up to a given height, and then subsequent layers of horizontal reinforcement are laid down. Afterwards, reinforcements are inserted vertically or at an inclined angle, as per the design requirements. Each layer is then tied to another so that it acts as one integrated system, reducing the total force at the back of the facing panels.

This concept is modelled numerically using PLAXIS 2D version 9.0 using the Kobe earthquake loading. The convincing results from this numerical analysis encouraged me to conduct an experimental program that included shake table tests. The selections of materials were then tested to determine which materials were readily available on the market. Four reduced scale physical models, with and without vertical reinforcement, with angled reinforcement towards the facing and against the facing were tested on a shake table under stepped-up sinusoidal acceleration input. The results of the four models tested were then compared to evaluate the performance enhancement of a soil

wall with vertical reinforcement. The results showed that the wall with vertical reinforcement improved its performance under dynamic loading remarkably.

Finite element models based on the same parameters used in the shake table experiments and with a PLAXIS 2D program were developed, from which the numerical outcomes generated similar patterns of better performance when vertical fortification was included. Those results are matched against the experimental outcomes, and the results show a reasonable agreement between the measured and calculated displacements, backfill surface settlements and accelerations, albeit there were some discrepancies. These slight dissimilarities could be the result of implementing, to some extent, different physical properties in the numerical model and their variability within the measured data. An array of parametric studies with varying design parameters was also carried out, with the results indicating that the magnitude of dynamic response increases with a decreasing angle of friction and the extent of dynamic response decrease with an increasing Young's modulus. It is also found that the vertical reinforcement with very close spacing (less than three times the spacing of horizontal reinforcement), adds no extra benefit for the wall system.

According to the findings of this study, the proposed inclusion of vertical components to reinforced soil walls enhances the stability of the walls compare to the conventional reinforced soil systems under earthquake loading. The vertical components increase the integrity of the reinforced wall and create blocking actions, which reduce deformations at both facing wall and backfill surface. These outcomes point out the potential benefits of inserting vertical elements into a conventional soil reinforcement system under dynamic loads.

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1. Latin Notations

A	Area of the shear surface
A_{vr}	Area of the shear surface of vertical reinforcement
c	Cohesion
c_{inter}	Cohesion of the interface
c_{soil}	Cohesion of the surrounding soil
C	Damping matrix
D	Damping ratio
D_{max}	Maximum damping ratio
E	Young’s modulus
F	Load vector
g	Gravity acceleration (9.8 m/s^2)
G	Shear modulus
G_{max}	Maximum shear modulus
h	Height of the specimen
H	Height of the wall
H_i	Height of vertical reinforcements at each layer
K	Stiffness matrix
K_{AE}	Total earth pressure coefficient
k_h	Horizontal seismic coefficient
k_v	Vertical seismic coefficient
L_a	Length of the anchorage
L_{vr}	Length of vertical reinforcement in anchorage zone
m	Shear distortion ratio
M	Mass matrix

M_D	Driving moment
M_R	Moment resistance due to the shear strength of the soil
N	Number of reinforcement layers
P_1	Horizontal force
P_{AE}	Total active earth force
$P_{AE\text{-}HOR}$	Horizontal component of total active thrust
$q_{u(R)}$	Total bearing capacity after the reinforcement
$q_{u(UR)}$	Bearing capacity of the unreinforced soil foundation
r	Radius of specimen
R_{inter}	Interface reduction factor
R_T	Tensile strength of the reinforcing materials per unit length
S	Shear force
S_Z	Spacing of reinforcements
T_i	Tensile force in the i^{th} layer of reinforcement
T_r	Tensile force
T_{vr}	Tensile strength of the vertical reinforcement
u	Depth of reinforcement location
u	Displacement vector
$\dot{u}$	Velocity
$\ddot{u}$	Acceleration
V_1	Vertical force
V_p	Compression wave velocity
W	Weight of the wedge
W_A	Weight of the static internal failure wedge

2. Greek Notations

β	Angle of the back slope
γ	Unit weight of the retained soil

γ_r	Reference strain
δ	Mobilised interface friction angle between the back of the facing wall and the backfill soil
ΔM_R	Increase in moment resistance due to the reinforcement
ΔP_{dyn}	Dynamic earth force
ΔT_{dyn}	Dynamic tensile reinforcement load increment
$\Delta T_{dyn\ i}$	Dynamic tensile reinforcement increment
ΔT_{vi}	Increased tensile force due to the vertical reinforcement
θ	Angle of inclination of the inside face of the wall to the vertical
λ	Inter-wedge shear mobilisation ratio
μ_v	Vertical reinforcing ratio
ν	Poisson's ratio
σ_1	Vertical stress
τ	Shear stress
τ_{max}	Maximum shear stress
ϕ	Friction angle of the retained soil
ϕ_f	Factored soil friction angle
ϕ_{inter}	Friction angle of the interface
ϕ_{soil}	Friction angle of the surrounding soil
ψ	Angle of seismic inertia
ψ	Dilatancy angle