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COMPARE INFLUENCES OF HORIZONTAL AND VERTICAL MSE WALL DIMENSIONS WITH GEOCOMPOSITE BACK DRAINAGE SYSTEM TO MAXIMUM STEADY STATE PHREATIC LEVEL

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Abstract. Nowadays, with serious risks to the mechanically stabilized earth (MSE) instability especially for soil mass (protected zone) behind the wall face caused by heavy rainfall. Come from high drainage ability, geocomposite is regarded as an appropriate material for drainage purposes in many geotechnical structures, including MSE walls. However, there are insufficient researches that investigated MSE wall geometry design especially with wall dimension oriented follow 2D dimension as horizontal and vertical. This paper presents a series of PLAXIS numerical simulations to investigate the influences of MSE wall dimensions and geocomposite drainage capacity on seepage responses inside the protected zone of the wall. The research results indicate that the distance from the upstream water source to the drainage face (L) influences most to the maximum steady-state phreatic level (h_o) variation inside the protected zone. In comparison, the horizontal wall dimension has more effects on h_o drops than vertical wall dimension.

Keywords: MSE wall; geocomposite; steady-state flow; wall dimensions; maximum phreatic level

1 Introduction

By wide advents and popular appearances of mechanically stabilized earth (MSE) wall with geosynthetics back drainage system led worldwide researches conducted academic and particle researches for deeply understanding and awareness in realistic situations. Many kinds of failures happened in MSE wall with back drainage system during long-term rainfall. MSE wall failure cases have been mentioned detail in many reports [1-4]. Through the maximum level changes of maximum steady-state phreatic level in the protected zone of MSE wall, h_o, reflects the effectiveness of the drainage system and also suitability selection of soil backfill and native in practical works.

There are a number of literature reported influence variables that affect the magnitude of h_o (Chinkulkijniwat et al. 2017, Bui Van et al. 2017, La Duong et al. 2021). However, very few of

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the previous attempts reported influence of MSE wall dimensions, especially for vertical and horizontal directions of MSE wall on the variation of phreatic surface in the protected zone. Also, few pieces of research did not integrate and quantify well the rise of h_o with all influenced factors that lead uncomprehensive research for practical wall design.

Based on the above statements, this study desires to comprehensively estimate the rise of h_o with assigned wall dimensions and geocomposite drainage system in successor from research of La Duong et al. (2021). Selected influenced MSE wall dimensions to h_o for this research comprise as horizontal dimensions as distance from the upstream water level to the drainage face (*L*); width of protected zone (*W*), and vertical dimensions as wall height (*H*); distance from the wall base to the impervious boundary (*D*). A well-calibrated numerical model, computed in the Plaxis environment and introduced by Chinkulkijiwat et al. (2017), was regarded as scaling influences (Figure 1). To be success on the validity of the Plaxis model with different scales, it was established using identical shape ratios at the double size of the physical model (Figure 2). Good estimation of h_o is essential for the reliable and appropriated design of MSE wall against failure. The conceptual research method used in this research is numerical analysis via Plaxis-2D environment. This research desires to give more practical suggestions for MSE wall construction with optimum geocomposite drainage capacity than previous researches as La Duong et al. (2021) and Chinkulkijiwat et al. (2017) in order to avoid negative impacts of groundwater level rising due to rainfall.

2 Research methodology

2.1 Research background

Steady-state flow conditions were the focus of this paper in order to quantify the final state of groundwater flow in the porous media. These conditions were focused for research objects as MSE wall. All values of h_o were extracted from the numerical experiment in PLAXIS-2D. Also, the van Genuchten model (1) [6] and van Genuchten-Mualem model (2) [5]. These conceptual equations are mentioned in La Duong et al 2021. All material hydraulic properties in this modelling are later named in this paper as VG and VGM model, respectively (Table 1). The models gave the following equations:

$$S_e = \frac{S - S_{res}}{S_{sat} - S_{res}} = \frac{\theta - \theta_{res}}{\theta_{sat} - \theta_{res}} = \left[1 + \left(\alpha \left|h_p\right|\right)^n\right]^{-m} \quad (1)$$

$$k_r(S_e) = S_e^{0.5}[1 - (1 - S_e^{1/m})^m]^2 \quad (2)$$

Which,

S_e - effective degree of saturation (-); S - degree of saturation (-); S_{res} - residual saturation at very high values of suction (-); S_{sat} - the maximum saturation of saturated soil (-); θ_{res} - residual volumetric water content (-); θ_{res} - maximum volumetric water content of saturated soil (-); h_p - matric suction head (m); k_r - relative permeability coefficient: α - VG model parameter; n - VG model parameter; m - VG model parameter;

2.2 Numerical analysis

Series of numerical experiment was conducted using the finite element code PLAXIS. Figure. 2 depicts the discretized finite element mesh for the MSE wall model and the shape parameters investigated in this study. The main flow mode was selected for this PLAXIS calculations as mentioned above as steady-state flow. Fifteen-node triangles were assigned to the generated models, and a fine mesh with an average element size of 0.05 m was selected. Finer mesh of fifteen-node triangle was also assigned to geocomposite back drainage system comprised as geotextile (sandwiched layers) and geonet (core drainage).

Table 1. Basic and relevant physical and hydraulic properties of studied materials [2-4] for this study.

Soil material	Physical properties of all materials				Hydraulic property and VG model parameters						
	γ (kN/m3)	Gs (-)	PL (%)	LL (%)		Permeability (m/sec)		α (m-1)	n (-)	Ssat (-)	Sres (-)
Sandy soil	15.0	2.74	-	-		1.97×10-4		20	1.5	1.0	0.03
Lateritic soil	18.27	2.75	26	42		4.0×10-6		0.8	1.4	1.0	0.2
Geosynthetic material	Porosity (-)	Open size (mm)	Weight per area (kg/m2)	Thickness (mm)	Permeability ×10-2 (m/sec)	Transmissivity ×10-6 (m2/sec)	Permittivity (sec-1)	α (m-1)	n (-)	Ssat (-)	Sre (-)
Geotextiles	0.9	0.15	0.339	2.5	2.3 (0.37)1	57.9 (9.26)2	9.23 (1.48)3	20	2.5	0.8	0.03
Geonet	-	-	1.0	5.0	80	0.004	160	600	40	1.0	0.0

Note: [1]Permeability of geotextile in lateral direction; [2]Transmissivity of geotextile in lateral direction; [3]Permittivity of geotextile in lateral direction.

As for boundary conditions, dirichlet boundary conditions with prescribed pressures were imposed on the left, right, and top boundaries of PLAXIS model, and the bottom boundary of the model was defined as impermeable. The left and right boundaries were set up with hydrostatic pressure conditions whereas the top boundary was assigned atmospheric pressure. Groundwater flow was simulated by applying hydrostatic pressure according to the upstream water level equal to any desired height. Time steps were automatically assigned by the software using a modified Newton-Raphson model. In each iteration, the increment of the groundwater head was calculated from the imbalance in the nodal discharge and added to the active head. This process continued until the norm of the imbalanced vector – that is, the error in the nodal discharge – was smaller than that of the error tolerance of 0.01 (or 1%).

For calibration purposes, the model was designed to replicate the experimental studies mentioned above (Figure 1). This model incorporated sandy soil, structural components (reinforced bar and acrylic facing), and drainage components (geotextile, and geonet). The seepage characters of the relevant materials were described using Eq. 1 and Eq. 2. To ensure the validity of the PLAXIS model on different scales, the PLAXIS model was established to keep identical shape ratios at double the size of the physical model: H = 2.0 m, H_w = 2.0 m, W = 1.6 m, and D = 0.8 m as mentioned detail in La Duong et al 2021 [4]. Furthermore, the thickness of geotextile and geonet was also enlarged 2 time thicker than that of the physical model, i.e. thickness values of geonet and geotextile were 10 mm and 5 mm, respectively.

Plaxis 2D software conducted a series of numerical simulations to investigate the individual effects of each horizontal wall dimension as L, W and vertical wall dimension as H, D on seepage responses, including the highest water level in the protected (h_o) inside the protected zone. All assigned dimensions were follow scenarios for Plaxis model set up shown in Table 2 during the numerical experiment. VG-VGM model and soil material parameter were kept constant for studied MSE wall dimension simulating. The water level at upstream (H_w) was also constant by 2.0 m as equal to wall height (H) for all simulations.

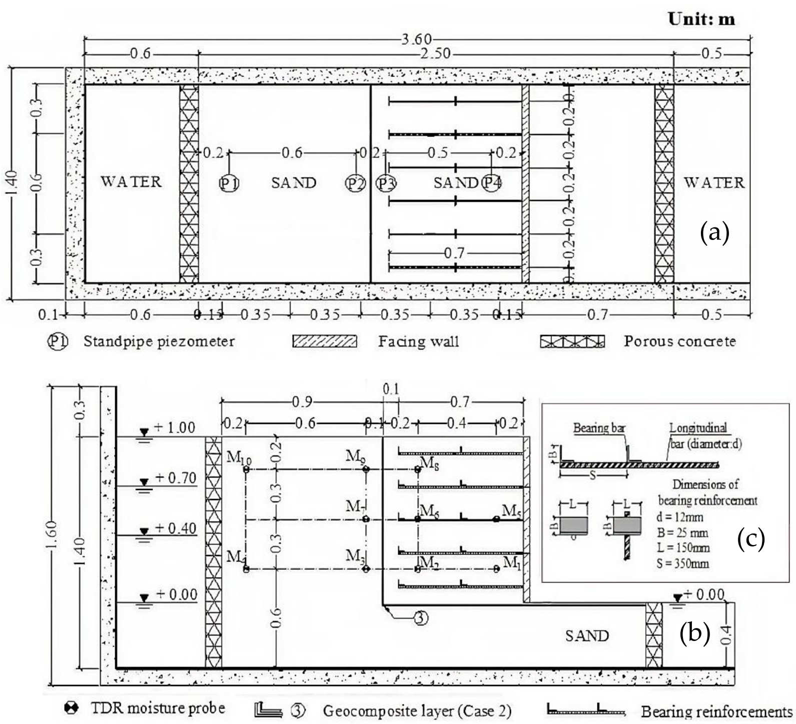

Fig. 1. Sketch of the physical test model and its instrumentation: (a) plan view and (2) side view of the model subjected to Chinkulkijniwat et al. (2017), Bui Van et al. (2017), La Duong et al. (2021)

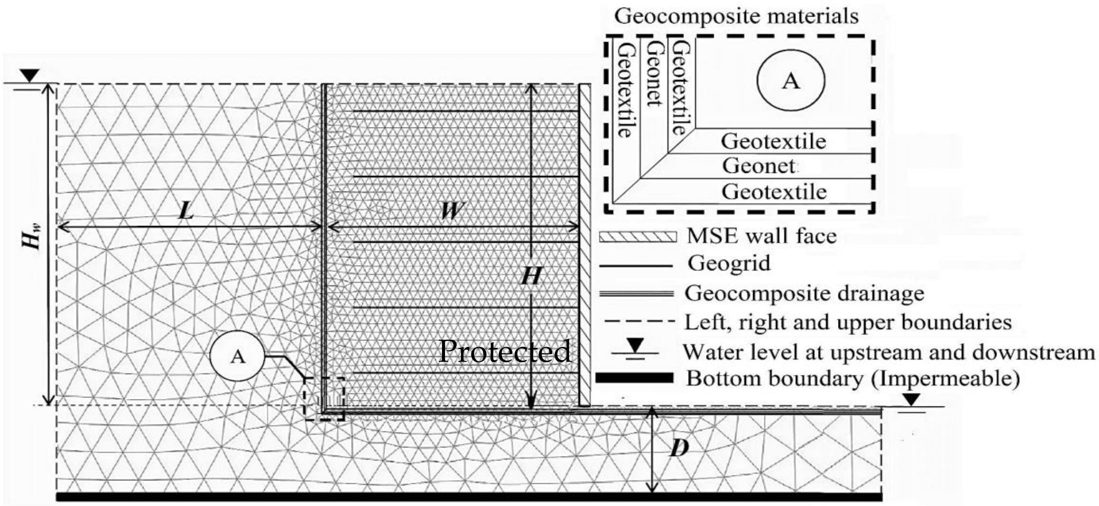

Fig. 2. Plaxis model of mesh discretization with h_0 and conceptual assigned MSE wall dimension as following horizontal and vertical direction with geocomposite back drain [4].

Table 2. Series of 66 simulations for this paper adapted from La Duong et al. (2021).

Material	Permeability (m/sec)	Thickness (mm)	α (m-1)	n (-)	Ssat (-)	Sres (-)
Sandy soil	1.97×10-4	-	20	1.5	1.0	0.03
Lateritic soil	4.0×10-6	-	0.8	1.4	1.0	0.2
Geotextile	0.023 (0.0037)*	5.0	20	2.5	0.8	0.03
Geonet	0.8	10	600	40	1.0	0.0

Scenarios	Native soil	Backfill soil
S-S	Sandy soil	Sandy soil
L-L	Lateritic soil	Lateritic soil
L-S	Lateritic soil	Sandy soil

Varied dimensions	Definition	Referenced value	Varied values
H (m)	MSE wall height	2.0	3.0, 4.0, 5.0
D (m)	Distance from the wall base to the impervious boundary	0.8	0.0, 0.5, 1.0, 2.0, 3.0, 4.0, 5.0
W (m)	Protected zone width	1.6	2.0, 2.5
L (m)	Length from upstream water to the drainage fac	2.0	0.5, 1.0, 3.0, 4.0, 5.0

3 Results and discussions

The variations of h_o for every horizontal and vertical wall dimensions and every scenario were plotted together (Figure 3) [4]. They argued that soil in the protected zone was more permeable in *L-S* scenario than in *L-L* scenario, therefore the flow path reflection resulted in the lower phreatic surface in the protected zone for *L-S* scenario than that for *L-L* scenario, in research of La Duong et al (2021). In his paper, there are a combination and intergrated between *H* and *W*, also called shape of MSE wall protected area behind wall face. That shape is standed on fixed ratio between *H* and *W*. However, this research attempt to modify and distinguish each MSE wall dimensions following assigned directions in differences from his paper. This is for providing deeper understading each MSE wall dimension behavior.

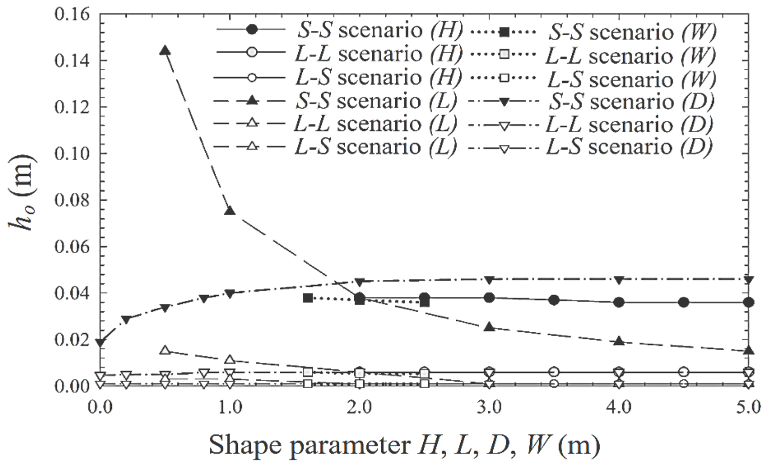

Fig. 3. Variation of h_o subjected to change in all shape parameters for S-S, L-L and L-S scenarios adapted from La Duong et al. (2021).

The significant difference of phreatic surface took place only near the drainage interface (Figure 4). However, their research did not conclusion much about the changes of h_o subjected to horizontal and vertical wall dimensions. This studied research results will continue and investigate about that issue based on findings of La Duong et al. (2021).

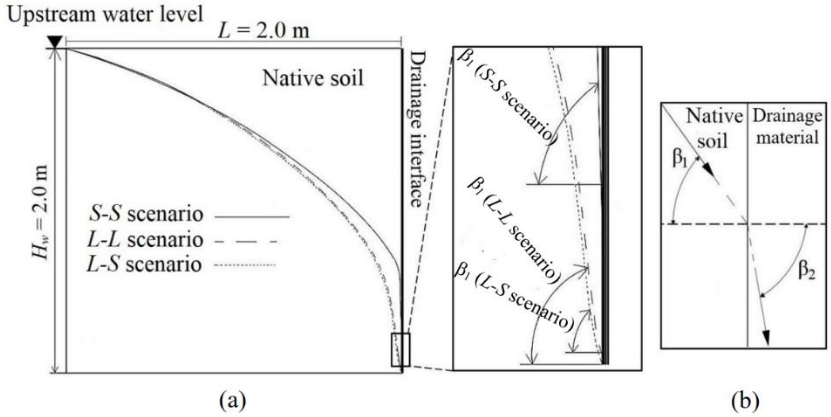

Fig. 4. (a) Phreatic surface approaching drain interface and (b) Reflection of flow directed from native soil to drain material subjected to [4].

3.1 Influences of horizontal wall dimension

Length from upstream water to the drainage face (L)

The longer the distance from the upstream water to the drainage face (*L*), the more the hydraulic head falls/head drops and with it the phreatic level at the downstream flow out. Figure 5 indicates the variability of with *L* shape parameter. When *L* is small, h_o drops rapidly; however, with *L* increments, that causes the rate of h_o fall reduces. In *S-S* scenario, the magnitude of h_o drops approached asymptote when the *L* shape parameter was greater than 4.0 m (approximately 200%) of the wall height. As for other cases as *L-L* and *L-S*, there were no change significantly of h_o. This key behaviour implies that the influence of *L* dimension was eliminated if it was enlarged as much. The increment of *L* is considered as the MSE wall construction is located far from the upstream in practice.

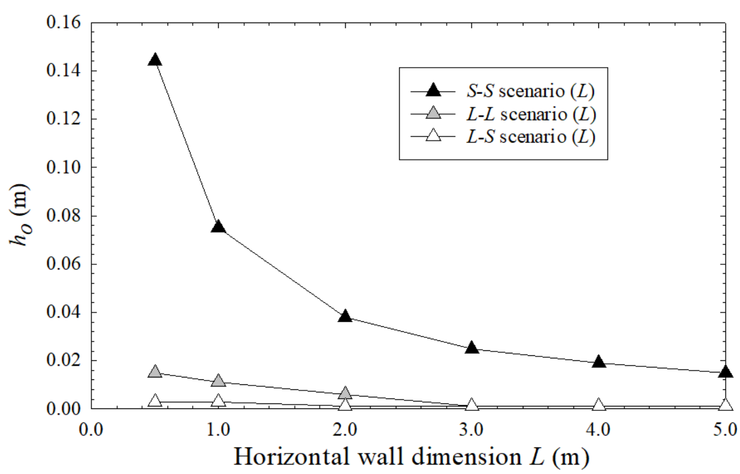

Fig. 5. Variations of h_o subjected to L dimension with all scenarios

In contrast, the phreatic height in the protected zone could be as high as 10% of the wall height when *L* was shorter than one fourth of the wall height. When MSE walls are installed in mountainous areas, the distance from the upstream water source to the protected zone can be very short. Accordingly, engineers must pay close attention to the potential phreatic levels in the protected zone of an MSE wall in mountainous terrain that is also concluded in La Duong et al 2021 [4].

Protected zone width (W)

The *W* wall dimension is considered as reinforced zone width and also the length of geocomposite at the bottom (Figure 2). The *W* varied from 1.6 to 2.5 m (Table 2). Based on based *H* and *W* value of 2.0 m (for this kind of simulation) and keep horizontal distance from upstream to downstream (*L*) water sources constant at 5.0 m, the h_o drops a little bit along with increase in *W* magnitude (Figure 6). The total change of h_o drops much slowly just 0.02 m in the range of *W* variation. It is shown that this variation of horizontal wall dimension *W* does not affect flow geometry in comparison to *L* dimension.

The clarification for this *W* behavior in these conditions is that the increase of W is corresponding connect to the bottom geocompisite drainage system. With 100 times higher of hydraulic conductivity (*k*) of geocomposite drainage materials than soil inside protected zone (ref. Table 1), so major water will penetrate through bottom drainage chanel to downstream, so that a ligh reduction of h_o for enlonging of *W* could obtain. However, this reduction is not much due to high water amount penetrated through wall base. The consideration of *W* changes is linked to practical suggestions for selecting the appropriated *W* adapted to mechanical and economical practical condition.

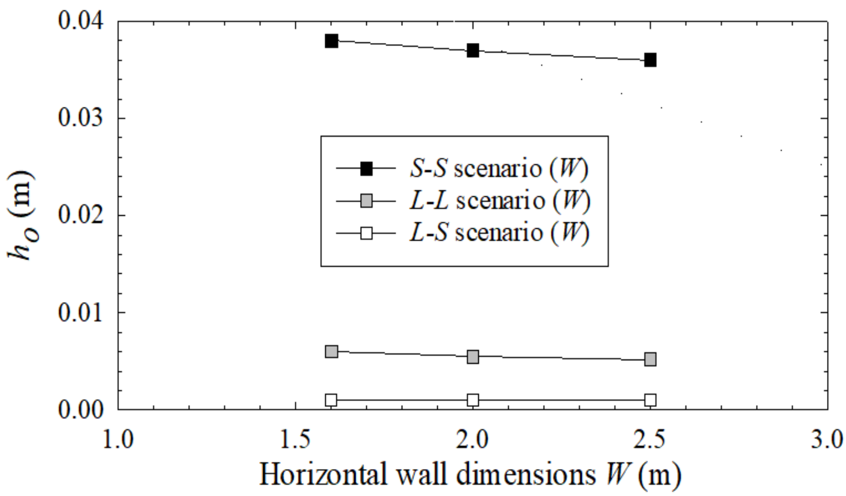

Fig. 6. Variations of h_o subjected to *W* dimension with all scenarios

3.2 Influences of vertical wall dimensions

MSE wall height (H).

Refer to wall height (*H*) is presentative to the back side of MSE wall protected zone. Also, keeping constant horizontal distance from upstream to downstream water sources constant at 5.0 m, the h_o indicates negligibly drops with *H* (Figure 7). As for the influence of the wall height (*H*) on the changes of h_o, since this wall dimension indicates no effect on the maximum phreatic level, the value of h_o did not change with *H* varying from 2.0 m to 5.0 m, as indicated in Figure 7. In research of La Duong et al (2021) [4], there was a h_o variations indicated via combined ratio between *H* and *W* such MSE wall protected zone shape, but this research was carried out independently for each wall dimension for *H* and *W*. This caused more detail understandings about h_o variations subjected to series of wall dimensions as *H*.

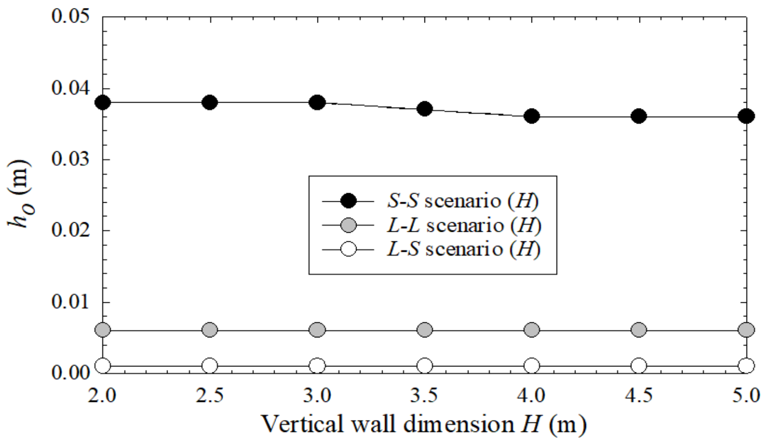

Fig. 7. Variations of h_o subjected to *H* dimension with all scenarios

Distance from the wall base to the impervious boundary (D)

For an MSE wall with geocomposite back drain installation, an increase of *D* distance resulted in a little rise of h_o as shown in Figure 3 and Figure 8. The incline of *D* dimension beyond 2.0 m did not change the h_o level. Noteworthy that the cases with *D* of 0.0 m were conducted to simulate impervious foundation at the wall base.

The enlarging *D* distance resulted in the drop of phreatic level since the sandy soil which located below the MSE wall could accept more amount of water flow. In field conditions, reduction of hydraulic properties as geonet - and geotextile transmissivities might be encountered by various factors; including creep, mineral/biological clogging, geocomposite intrusion, damage on implementation, discontinuity at the connection, etc. The conclusion drawn in this study appears valid if the geocomposite drainage capacity is still in normal working.

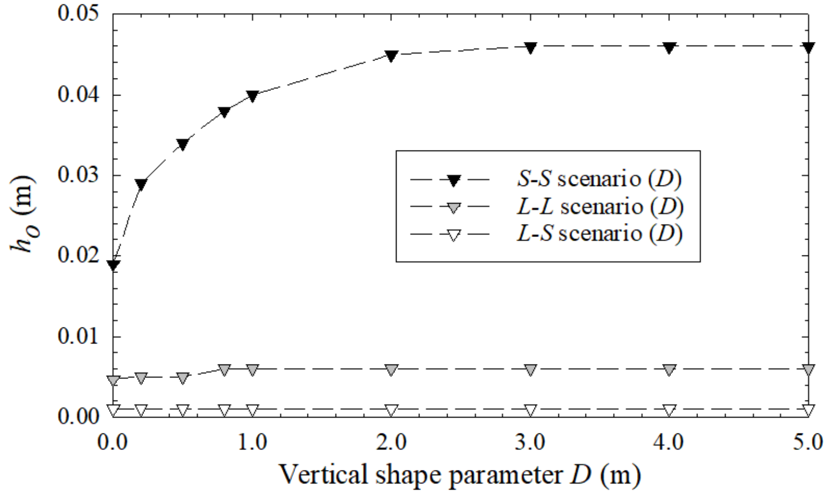

Fig. 8. Variations of h_o subjected to D dimension with all scenarios

4 Conclusions

The following conclusions were drawn from this study:

- The increase of horizontal wall dimension plays more significant roles on the drop of h_o than vertical wall dimension. Especially L wall dimension has a considerable influence on seepage responses in the MSE wall. Accordingly, involved engineers must pay close attention to the phreatic level in the protected zone when dealing with an MSE wall in a mountainous area, where the distance from upstream water to the drainage face might be very short.
- Obviously, vertical wall height (H) and the width of protected zone (W) play an inconsiderable role in the magnitude of h_o. In addition, the vertical distance from the wall base to impervious boundary (D) also has no effects on the variations of h_o. This conclusion is based on the assumption that the geocomposite drainage capacity works as normal without any water exceeding from drainage system.
- Varied behaviours of horizontal and vertical MSE wall dimensions in this paper emphasized more suggestions for MSE wall in practical design with optimum geocompisite drainage capacity. Especially, those results more indacted focus on complex construction sites in mountainous areas where MSE wall construction is commonly used.

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