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Soil nailing as a ground reinforcement method of a storey building constructed on weathered siltstone: Analytical and numerical evaluation

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ABSTRACT

The stability and load-bearing capability of an existing building/structure are primarily dependent upon its foundation. Current research and design standards require the foundation of any building must be able to withstand both passive and active loads, as well as dynamic ones. Yet, due to the changes in the ground conditions beneath the structure or additional loads applied, unexpected alterations could occur. Consequently, the foundation itself is unable to resist additional stresses. In some cases, the building could be subsided due to ground instability, especially in the case that the structure is situated on the weathered ground. Thus, the foundations require reinforcements. The paper presents a case study on the use of in-situ reinforcement technique, namely soil nail, to stabilize a shallow foundation of an existing building constructed on weathered siltstone. The two-dimensional limit equilibrium method was employed to evaluate the stability of the existing foundation with/without incorporating soil nail elements. The analytical results show that the stability of the foundation, presented in terms of the factor of safety, increases with the case of placing the soil nail elements underneath the shallow foundation. Moreover, the angle of the design cut-slope also affects the global stability of the foundation. Lastly, the single-wedge failure mechanism with the planar sliding surface is applicable to aid geotechnical engineers in quickly assessing and choosing the reinforcing method for the ground of footing due to its simplicity of calculation procedure and ease of interpretation of results.

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1. Introduction

In recent years, the expansion of the land area for infrastructure construction and other utilities has become more popular, especially in urban areas. This leads to the narrowing of the foundation area of existing buildings, consequently, the stability of present buildings is affected. Thus, the ground of those buildings must be reinforced. Among the common improvement techniques, placing reinforcement layers, such as galvanized steel strips, geotextiles, geogrids, and geocell, in the soil mass below a ground foundation has been widely used (Avesani Neto et al., 2013; Chakraborty & Kumar, 2014; Hou et al., 2017). The soil nailing technique is also commonly used to reinforce natural soil slopes and deep excavations (Phear et al., 2005; Sharma et al., 2019). However, it is still rarely applied to strengthen the ground of shallow foundation. To evaluate the effectiveness of the improvement techniques, several methods have been developed including the analytical, numerical, and experimental approaches (Chakraborty and Kumar, 2014; Hou et al., 2017). In those approaches, the stability of reinforced soil is normally estimated via its settlement, bearing capacity, and factor of safety. The analytical method used in the present study is developed based on the concepts of limit equilibrium, in which the potential sliding mass is modeled either as a rigid block or a series of slices. Additionally, Potgieter & Jacobsz (2019) did figure out the factor of safety (FS) of nailed wall computed from the conventional wedge and slices methods equate well.

The paper aims to examine the stability of a weathered siltstone ground of an existing shallow foundation strengthened by soil nailing technique using a single-wedge failure mechanism with the planar sliding plane. Consequently, the aptness of such a simple planar surface method on estimating the deep-footing stability analysis is evaluated. The findings of this practical case study could assist geotechnical designers in choosing an appropriate strengthening method for the shallow foundation, following the rule simple the better especially in practical engineering applications. As predominantly explained to fulfill primary objectives of the work on analyzing ground conditions of shallow foundation stability problems, two prevalent methods are used, namely limit equilibrium method (LEM) and finite element method (FEM).

2. Two-dimensional limit equilibrium method

Among the sophisticated methods of analyzing the stability of natural or reinforced shallow ground and cut slopes (i.e. soil nailed slope), the two-dimensional limit equilibrium is commonly used. In the LEM, a potentially sliding mass is formed either as a rigid block or a set of slices. When global equilibrium is considered, the factor of safety (FS) value is expressed as the ratio of resisting forces to driving ones by considering various potential slip surfaces. The slip surfaces are then examined until a critical one corresponding to the smallest factor of safety is found. The common solutions developed based on concepts of limit equilibrium are planar (single wedge) failure method, circular slip surface, friction circle method, vertical slice methods (Bishop, Janbu, Spencer, Abramson et al., 2001). Considering the ground conditions characteristics (homogeneous weathered rock mass or having only a single soil layer within the ground profile) and geometric condition of the slope, the suitability of the planar failure analysis method on estimating the stability of ground of a shallow footing is examined. Another reason is to present the analysis in two dimensions what makes it easy to understand and interpret the results. Such an approach also allows using a limited amount of input data. As such, this method could aid geotechnical designers in quickly assessing the reinforcing methods for slopes or retaining walls.

Number of researches available in the literature have shown that planar slope failures take place when a mass stone in a slope does slide down and along a relative planar failure surface. From a practical point of view, the planar failure is relatively rare, but it's still valuable for providing an insightful understanding of the behavior of weathered siltstone retaining walls, and hard rock slopes in general.

2.1. Without nail elements

The single wedge failure mechanism of the vertical cut slope is presented in Figure 1. As seen in Figure 1a, there are two possibilities that could lead the planar failure to take place: the first is when a single discontinuity is considered, the second reason is a series of discontinuities form a single plane to initiate failure of a cut-slope. Due to sliding forces like gravity, the unstable wedge tends to move along the sliding surface AB. In such case the factor of safety (FS) defined using LEM is as follows:

$$\text{FS} = \frac{Shear\ Strength, \tau_f}{Shear\ Stress, \tau_S} \quad (1)$$

Where: τ_f - shear strength of soil determined based on Mohr-Coulomb criterion:

$$\tau_f = \text{c} + \sigma\tan\emptyset \quad (2)$$

σ - normal stress: $\sigma = \frac{(W+Q)cos\psi}{A}$;

c - cohesion contributing to the strength of the soil.

∅ - the internal friction angle of soil.

Shear Stress: $\tau_S = \frac{(W+Q)sin\psi}{A}$

Q - surcharge load.

Length of the planar failure plane AB:

$$\text{L} = \frac{H}{sin\psi}$$

A - the area of failure surface: (L x 1), m^2 (unit thickness of slope is assumed).

W - weight of the unstable wedge, determined based on the trigonometric relationships shown in Figure 1a, expressed by an equation:

$$\text{W} = \frac{1}{2}\gamma\text{H}^2(cot\psi - cot\beta) \quad (3)$$

Therefore, the factor of safety concerning normal stress only is computed as follows:

$$FS = \frac{cL + (W+Q)cos\psi tan\emptyset}{(W+Q)sin\psi} \quad (4)$$

2.2. With nail elements

Findings from a number of researches indicate that both bending and shear strength of reinforcing elements, such as soil nails, play a trivial role in global stabilization of vertical reinforced slope (wall) Jewell & Pedley (1992), so only nail tensile force (T) is taken into account as shown in the Figure 1b. The magnitude of nail tension, T, is estimated by the pull-out resistance of the soil nail. The pull-out resistance equals either bond strength between the nail and surrounding soil or tensile strength of the steel nail.

As seen in Figure 1b, in the case of a vertical cut-slope where soil nails are present, driving forces comprise the weight of the sliding mass (W) and surcharge load (Q). The resisting forces along the planar surface are the same as in the case where soil nail is not incorporated. The difference is due to the fact that the nail tensile force is contributed by nail elements. To specify:

- For each soil nail element crossing the sliding surface, the nail's tension part parallel to a sliding surface having a magnitude, T_{pa}, of $T_i\cos(\psi+\alpha)$;

- For each nail element intersecting the sliding surface, the added frictional shear resistance induced by each nail element's tension part normal to the sliding surface; this tension part results in additional soil-to-soil friction having a magnitude of $T_i \sin(\psi + \alpha)\tan\phi$.

Thus, based on the trigonometric relationship shown in Figure 1b, as well as the fundamental concepts of FS in LEM, the magnitude of FS in the case of installing soil reinforcement (soil nail elements) is computed using the following equation:

$$FS = \frac{cL + (W+Q)cos\psi tan\phi + T_{nail}}{(W+Q)sin\psi} \quad (5)$$

$$T_{nail} = \sum_{i=1}^{n}[T_i\cos(\psi+\alpha) + T_i\sin(\psi+\alpha)tan\phi]$$

Where: n - the total number of nails used; T_i - the nail tensile force per unit length of horizontal spacing of ith nail determined as follows Su et al. (2010).

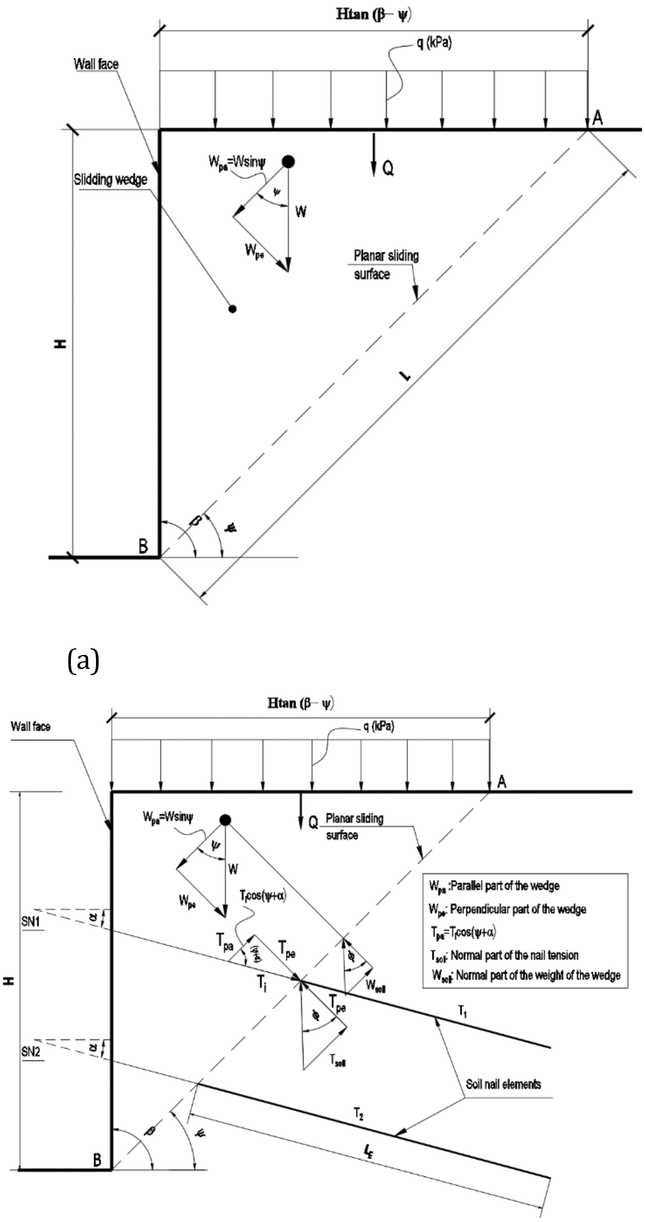
$$\text{T}_\text{i} = (l_e\ x\ P_{pullout})/S_h \quad (6)$$

Or, $$\text{T}_\text{i} = \frac{(c+\sigma_v tan\theta_m)pl_e}{s_h} \quad (7)$$

Where: $\theta_m = \frac{2}{3}\emptyset$ - mobilized soil-nail interface frictional angle; l_e - length of the nail behind the failure surface; p - perimeter of the nail; s_h - horizontal spacing of nails.

$$\sigma_v = \gamma h_i + q\ (\text{kPa}) \quad (8)$$

The definition of FS in equation 5 has been presented in the current practice code (Lazarte et al., 2015; Sivakumar Babu & Singh, 2011). For better understanding Table 1 is provided which shows the analytical equations for estimating factor of safety of vertical retaining wall with and without soil nail elements.



(a)

(b)

Figure 1. Side profile scheme of a single-wedge failure mechanism: (a) without soil nails, (b) with nail elements.

Table 1. Analytical equations for calculation of factor of safety of cut-slope against failure.

Contents	Equations
Without soil nail	$FS = \dfrac{cL + (W + Q)\cos\psi\tan\emptyset}{(W + Q)\sin\psi}$
With soil nail	$FS = \dfrac{cL + (W + Q)\cos\psi\tan\phi + T_{nail}}{(W + Q)\sin\psi}$

3. Presentation of case study

3.1. Geotechnical conditions

Geotechnical conditions were evaluated by implementing the standard penetration test (SPT test). Disturbed soil samples were collected during the SPT test, all the soil samples were tightly fastened to maintain their natural moisture content before carrying out laboratory tests. The results of the geotechnical investigation show that the existing building is constructed on highly weathered siltstone with a thickness of 16.9m (level of +31.40), average Total Core Recovery (TCR) and Rock Quality Designation (RQD) values obtained from core drilling were of 12÷38%, and 0%, respectively. The unconfined compressive strength (UCS) test results show that the average values of UCSs were 21.7 MPa and 14.7 MPa for dry and saturated conditions. The magnitude of compressive strength obtained from dry and fully moistured conditions indicates that the strength of weathered siltstone is significantly affected by the moisture content. As the siltstone gets weathered, the bond strength between soil particles decreases, consequently, the compressive strength and tensile strength of the weathered stone are reduced. According to Sivakugan et al. (2014), unlike soils, rocks indicate significant tensile strength with a value equal to (1/5÷1/20) of its compressive strength. Additionally, shear strength parameters such as internal friction angle could be derived from compressive strength and tensile strength values.

$$\emptyset = sin^{-1}(\frac{\sigma_c - 4\sigma_t}{\sigma_c - 2\sigma_t}) \quad (9)$$

Where: σ_c - compressive strength (MPa); σ_t - tensile strength (MPa).

The value of weathered siltstone deformation modulus was estimated based on the empirical equation proposed by Hoek & Diederichs (2006); Małkowski et al. (2018), in which the deformation modulus of siltstone is estimated based on a uniaxial compressive test, as follows:

$$E = 0.149UCS - 1.959 \quad (10)$$

$$E = (350 - 400)UCS, MPa \quad (11)$$

It is noted that the unit of UCS in equation (10) is in MPa, while E is in GPa. Summary of soil properties is shown in Tables 2 and 3. The smallest value of E estimated from equations (10) and (11) was taken into consideration. This is to ensure the stability of the existing building under the most unstable condition. According to the soil investigation, there was no groundwater table found from the surface to an elevation of +23.00 (~ 21.50 m depth from the surface level of +44.5). The physical and mechanical properties of the weathered siltstone are summarized in Table 2.

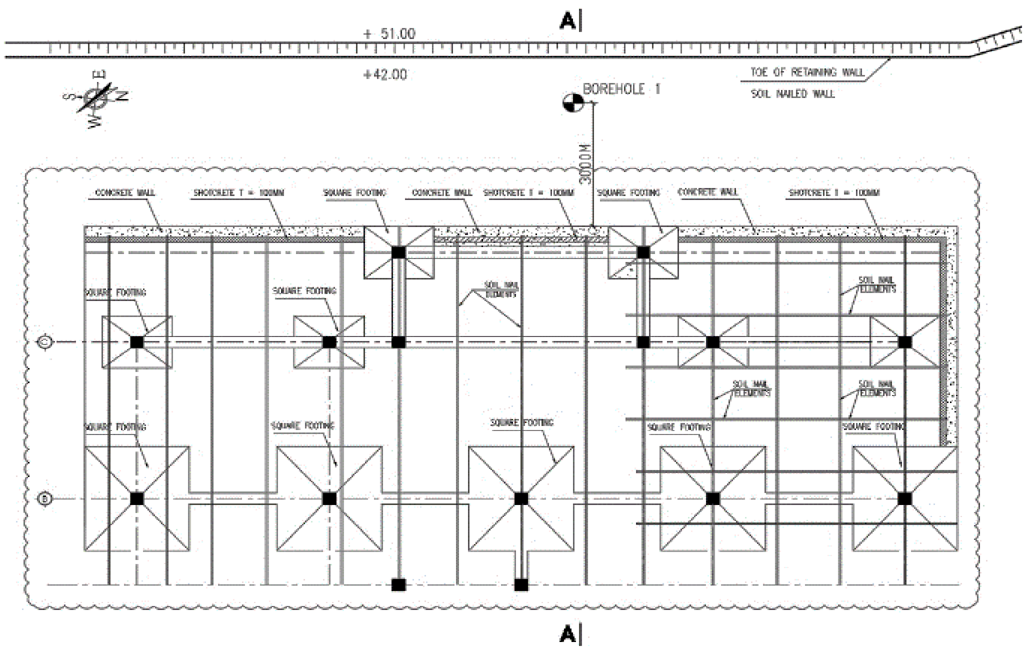
Table 2. Summary of physico-mechanical properties of weathered siltstone.

Descriptions	Unit	Values
Specific gravity, Gs	g/cm³	2.66
Void ratio, e	-	0.5-0.7
Porosity, n	%	35-42
Saturated unit weight	g/cm³	2.487
Dry unit weight		2.477
moisture content	%	0.4
TCR	%	12-38
RQD	%	0
UCS		
Natural	MPa	21.76
Saturation	MPa	14.68
Friction angle	Degree	36.87
Cohesion	MPa	0.05

3.2. Geotechnical conditions

A three-storeyed building was constructed in a coastal city in Vietnam. The geotechnical investigations revealed that the ground profile of the building area comprised mainly of a weathered siltstone rock. The foundations were designed to bear a column load of 550 kN, assuming 137.5 kN/m² safe bearing stress of the weathered siltstone. To meet the requirements, single column footings of 2.0 m x 2.0 m dimensions were proposed. In its original design, the shallow footings of the building were constructed at a level of +44.5 (as shown in figure 2). However, to fulfill a plan a new infrastructure system, an access road close to the building needs to be provided and must be extended. Therefore, the surface of the building was excavated from its current level of +44.5 to +42.00. It was then necessary to reinforce the soil beneath the foundation of the building. Soil nailing technique has been chosen to improve the ground conditions. The soil nail was designed according to FHWA-NHI-14-007 (Lazarte et al., 2015):

- Soil nail elements were made of a solid bar with a diameter of 25 mm, and installed in a square pattern,
- Nail spacing in both directions were the same, S_h x S_v: 1.0 x 1.0 m,
- Length of the soil nail was 5.0 m,
- Nail inclination was 15 degrees.



(a)

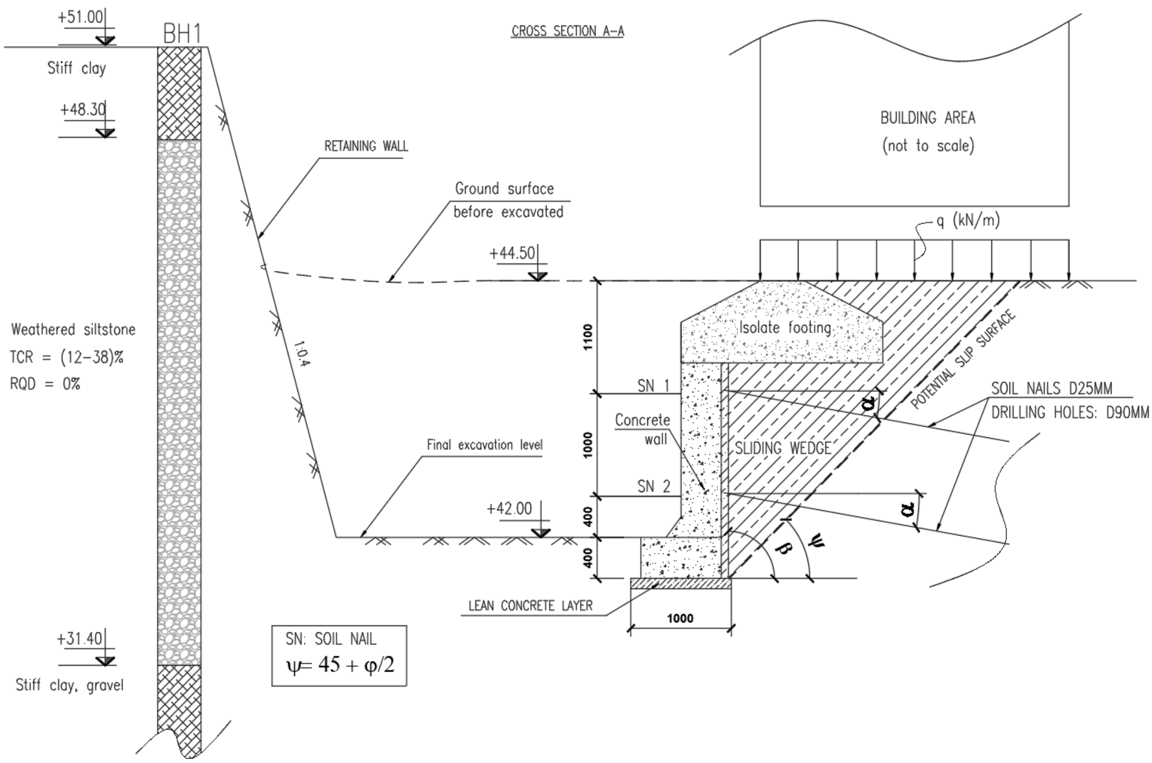


Figure 2. (a) Plan view of shallow foundation; (b) Typical cross-section of ground condition underneath the building.

4. Results and discussions

To estimate the effectiveness of the improvement technique of placing reinforcement layers underneath the foundation as well as to verify the single-wedge failure mechanism with planar sliding surface, both analytically based concepts of LEM and the numerical analysis using 2D FEM were employed. The geometry model and boundary conditions are shown in Figure 4. The soil model was adopted using the Mohr-Coulomb criterion and the soil nail is modeled as an elastic material. Load distribution of 137.5 kPa was applied. The nail elements were simulated using geogrid element, with their equivalent modulus estimated using the equation:

$$E_{eq} = \frac{E_{grout}A_{grout} + \left(\frac{A_{steel}}{A_{grout}}\right)E_{grout}}{A_{nail}} \quad (12)$$

Hence, the axial stiffness of nail element is defined as below,

$$EA = \frac{E_{eq}A_{nail}}{S} \quad (13)$$

The properties used for the materials are summarized in Table 3.

Table 3. Input parameters for FEM.

Descriptions	Units	Values
Soil properties		Elastic
E_{ref}	MPa	5000
Cohesion	MPa	0.05
Frictional angle	Degree	36.87
Dilation angle	Degree	6.87
Poisson's ratio	-	0.30
Dry unit weight	kN/m^3	24.7
Saturated unit weight	kN/m^3	24.87
Void ratio	-	0.67
Soil nail elements		Geogrid
Material type		Elastic / Geogrid
Bending stiffness, EA	kN/m	1.0E5
Nail diameter	mm	25
Drill hole diameter	mm	90
Nail inclination	Degree	15
Compressive strength of grout	MPa	40

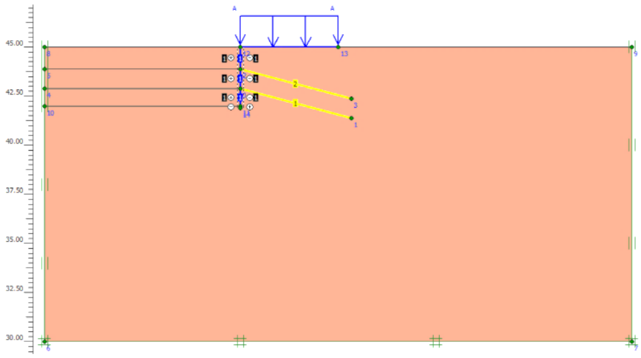


Figure 3. Finite element model with boundary conditions.

4.1. Overall stability

According to Geoguide 7 (GEO, 2008) the minimum factor of safety against failure for new soil nailed cut slope along a potential failure surface is dependent on the consequence of the failure. Since the consequence of the failure of the nailed slope in the study is in respect of loss of life, so the minimum factor of safety of 1.4 was used as design value Figure 3.

The overall stability of the ground foundation was estimated using the two-dimensional limit equilibrium concept. Thus, the single wedge with the planar surface was employed. The analytical results show that the factors of safety were 1.5 and 0.87 for case 1 (with) and case 2 (without soil nail elements), respectively. The value of 0.87 indicates that the stability of the vertical retaining wall does not meet the required minimum value of factor of safety recommended by both Guide to Soil Nail Design and Construction (GEO, 2008) and FHWA 2015 (Soil nail walls reference manual). To ensure the building safety (after soil excavation), the ground underneath the shallow footing, as well as the vertical retaining wall, must be reinforced. Higher the factor of safety gained greater the contribution to the tensile strength, Ti, of the soil nail installed. This lays in a good agreement with the statement of the findings presented by Jewell & Pedley (1992).

The value of FS obtained from the LEM was also compared with that obtained from the strength reduction factor in the FEM. The comparison indicates that both means provide a similar trend of stability of the retaining wall, as shown in Figure 4. In terms of quantitative analysis, the magnitudes of FS obtained from the equilibrium method agree well with those estimated from the finite element shear strength reduction technique. This concerns the case of without soil nail element especially. Computed results of the present work fit with those published by Cheng et al. (2007). Yet, the values of FS obtained by LEM, and FEM differ from each other. This is due to the LEM estimates the factor safety at serviceability state, while the strength reduction technique (used in FEM) calculates FS at the ultimate state as presented in Potgieter & Jacobsz (2019).

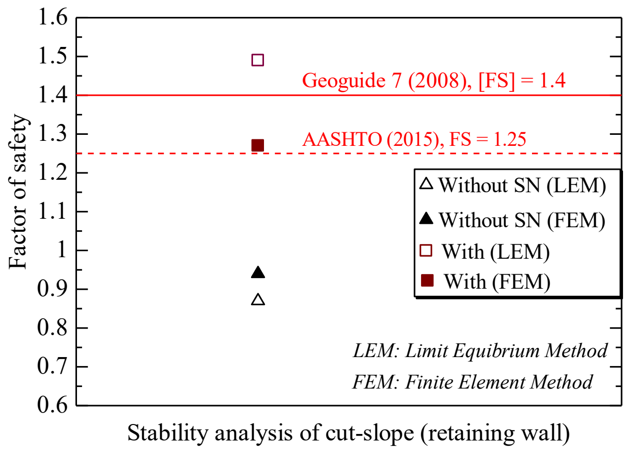


Figure 4. Stability of reinforced wall estimated from analytical and strength reduction methods.

Additionally, to ensure the preliminary length of soil nail elements satisfies sliding stability requirements, the location of shear failure was primarily computed as shown in Figure 5. It shows that the length of the nail element beyond the sliding failure. A view of the case study site with the reinforcing element's location is provided in Figure 6.

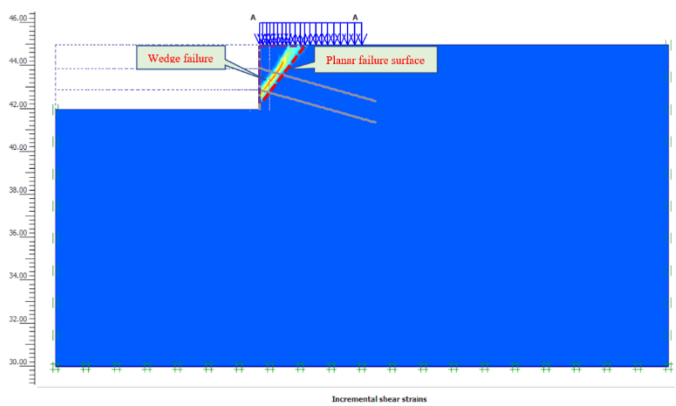
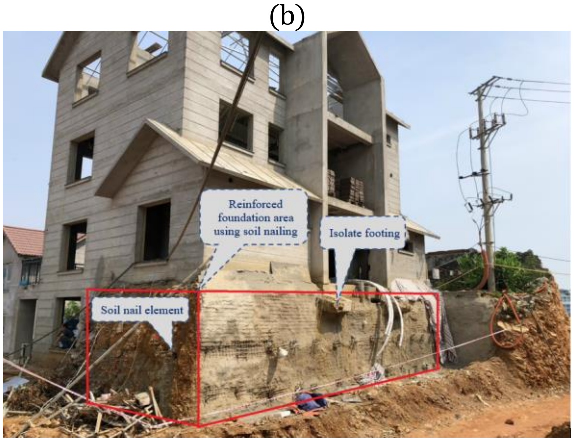


Figure 5. Failure zone in the numerical model.

(a)

(b)



(c)

Figure 6. Strengthening the ground: (a) before; (b) during, and (c) after reinforced.

4.2. Displacements

Recent codes of practice for strengthened/reinforced soils requires the maximum long-term deformations of soil nailed wall such as lateral, δh, and vertical displacemnts, δv, must be less than tolerable deformation limits for the wall (δh, and δv are shown in Figure 7). The magnitudes of those deformations are estimated using the following equation (Australian 4678, 2002; BSI, 2011; GEO, 2008; Lazarte et al., 2015):

$$\delta_v \cong \delta_h = (\frac{\delta_h}{H})_i H \quad (14)$$

$(\frac{\delta_h}{H})_i$ - a ratio that is dependent on soil conditions as shown in Table 4 (Lazarte et al., 2015).

Table 4. Parameter values used in deformation calculations according to equation (14).

Variables	Types of soils		
	Weathered rock and stiff soils	Sandy soils	Fine - grained soils
$(\frac{\delta_h}{H})_i$	1/1,000	1/500	3/1,000
C	0.8	1.25	1.5

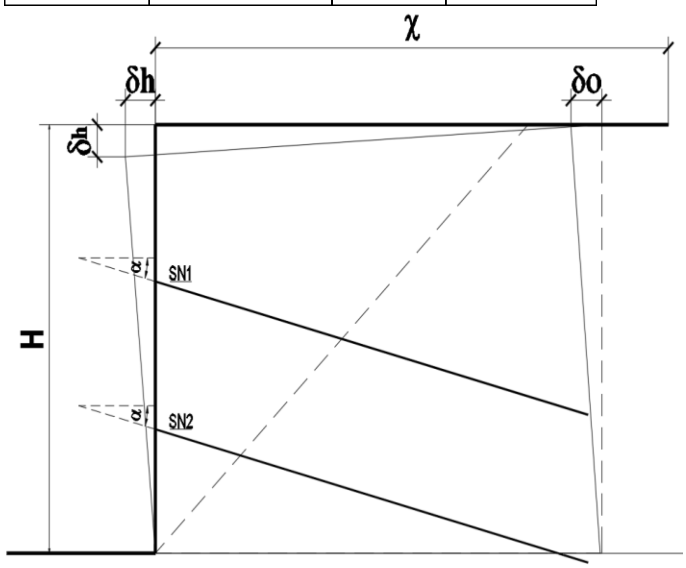


Figure 7. Deformation of soil nailed wall adopted from Lazarte et al. (2015).

Distance of significant soil deformation behind the wall, λ, is estimated as follows:

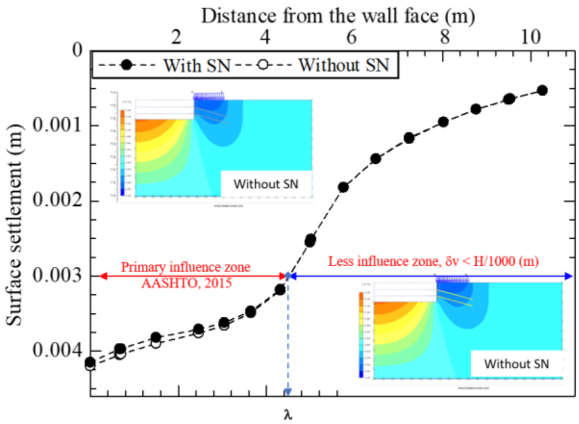
$$\lambda = H(1 - tan\alpha)C \quad (15)$$

Where: α - wall batter angle.

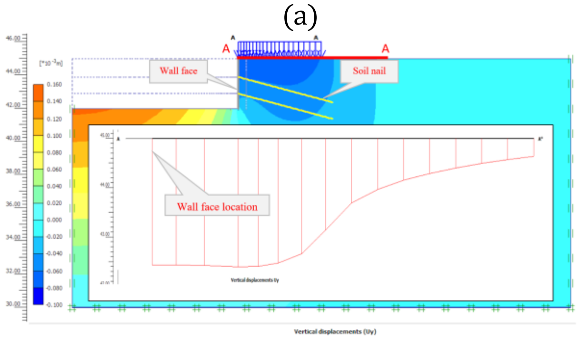
Based on those explanations, the maximum long-term displacements and length of the primary influence zone are: 0.003 m, and 2.4 m, respectively. These two magnitudes are used to evaluate the effectiveness of the soil nailing technique for the improvement of shallow foundations.

4.2.1. Vertical displacement

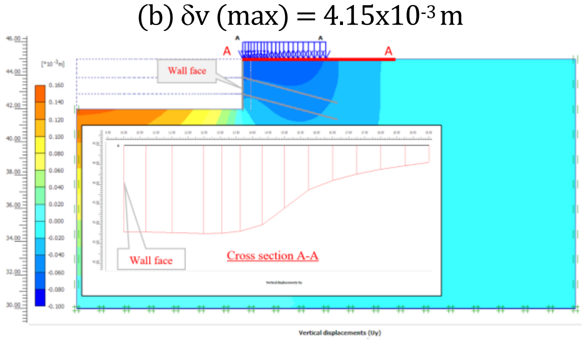
Figure 8 shows the vertical displacement distribution of the surface (computed at a level of +44.50). It can be inferred that as the ground is reinforced by soil nail elements, the settlement of the ground at the wall face is reduced from 4.20×10^{-3} m to 4.15×10^{-3} m for case 2 (without) and case 1 (with soil nails), respectively. In other words, by installing the soil nail, the bearing capacity of the ground could be improved as indicated by the decrease of settlement of the ground. However, the magnitude of ground settlement for the two cases was found to be the same at around 4.4 m far away from the wall face.



(a)



(b) δv (max) = 4.15×10^{-3} m



(c) δv (max) = 4.20×10^{-3} m

Figure 8. Surface settlement distribution of two scenarios (a), (b) with, (c) without soil nail.

The maximum settlement occurs at the wall face for both cases. Additionally, taking a maximum long-term deformation of 0.003m (according to AASHTO, 2015) into consideration, the distribution of settlements is divided into two zones. These are a significant influence zone and a secondary one. In the latter one, the length of the primary influence zone is 4.4 m or the length of primary influence zone λ ~ 1.3 H, H is excavation depth. The distance of significant soil deformation behind the nailed wall is almost two times longer than the estimated value of 2.4 m obtained from FWHA, 2015. This could be attributed to the contribution of the soil nail stiffness, axial and bending, for instance, driving to stability improvements of excavations (Shiu & Chang, 2006).

4.2.2. Horizontal displacement

Trends of horizontal displacement of wall face at the final excavation stage for the case of the slope reinforced by soil nail and without soil nail element is presented in Figure 9. Figure 9 is inferred that the placement of soil nail elements underneath the footing has a significant effect on the horizontal displacement of the wall. Without the soil nail elements, the magnitude of lateral displacement of the wall was found to be larger than that obtained from the case of installing soil nail elements. The set of result prove the effectiveness of the use of soil nailing technique for improvement of the ground conditions for the building constructed on weathered siltstone rock.

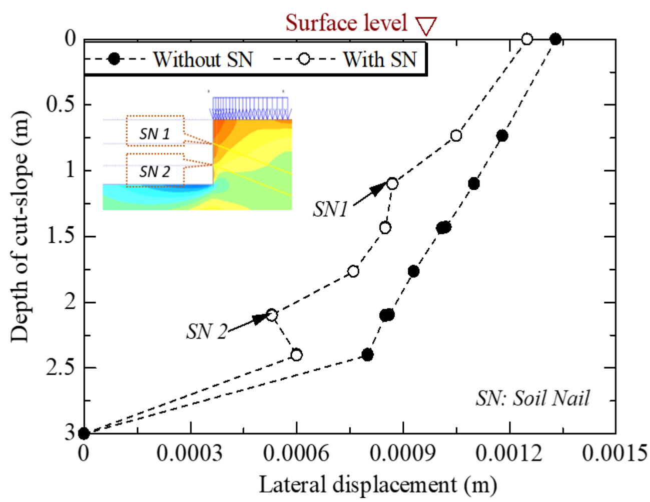


Figure 9. The trend of horizontal displacement of wall face.

4.3. Influences of retaining wall gradients

As previously stated, due to limited space at the construction site, to ensure the retaining wall geotechnical safety, the retaining walls inclinations on both sides of the building were reengineered to HD/VD, less than 0.25 (HD: Horizontal Distance; VD: Vertical Distance). Meanwhile, the supporting structure needs to hold the soil mass behind it. Based on those conditions, a set of cut-slope ratios were examined before designing the improvement method using soil nailing technique. Ratios for each scenario is presented in Table 5, Figure 10.

Table 5. Retaining wall gradients.

Study scenarios	Retaining wall ratios, H : V	Remarks
1	0.05	HD: Horizontal Distance VD: Vertical Distance
2	0.1	
3	0.15	
4	0.2	
5	0.25	

Analytical results presented in Figure 10 indicate that as the wall inclination increases, the factor of safety decreases. This is related to the increase in the weight of the wedge of the failure zone (the zone between the sliding failure plane and the wall face). The higher value of wall inclination the heavier weight of the wedge of failure generated. Thus, a lower value of FS is gained. For the case without soil nails, the designed wall gradients (H/V) must be larger than 0.05 and 0.1, to meet the minimum required values of FS according to FHWA, 2015 (Lazarte et al., 2015) and Geo 7 (GEO, 2008), respectively. In other words, at the expected wall angle of 90^0, the factor of safety estimated using LEM does not satisfy any considered standards. However, once the soil nail elements are placed in the ground, the required factor of safety of 1.4 is gained even at the wall angle of 90^0. For the case without soil nail elements, to reach the minimum factor of safety the wall gradient ratios must be H:V = 0.16, and H:V = 0.21 (according to AAHTO, 2015; GEO, 2008), respectively.

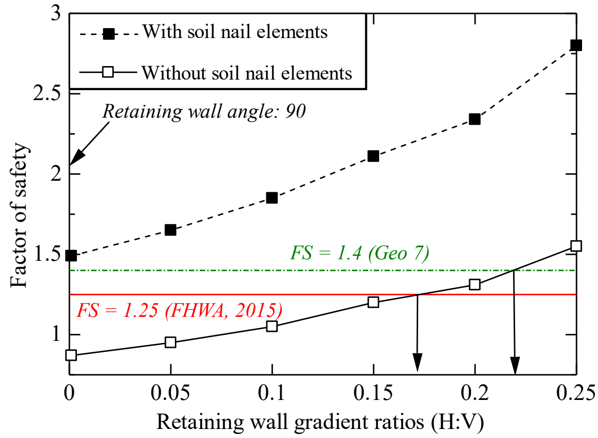


Figure 10. Effects of wall inclination on the stability of the ground.

4.4. Influence of nail's configuration

According to design standards of soil nail wall specified in BS 8006-2:2011, AASHTO 2015 (BSI, 2011; Lazarte et al., 2015), the nail spacing for a slope with its face angle range of 60 to 90 degrees should be from 0.75 m to 1.5 m. Accordingly, such range of parameters was taken into consideration to analyse the influences of the nail's configuration on the stability of the excavated wall. To evaluate the effects of nail spacing on the overall stability of the ground, soil properties, nail length, nail inclination, and wall inclination were assumed to have remained constant. Figure 11 shows analysis results of spacing effects on the factor of safety. The overall factor of safety decreases as the nail spacing increases. This result is due to the increase in the area assisted by the nail as the nail spacing increases.

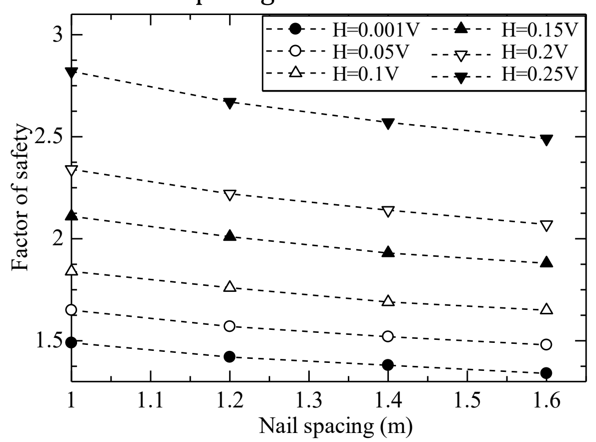


Figure 11. Effect of nail spacing on cut-slope stability.

However, care must be paid to the nail spacing because closely spaced nail elements could lead to stress overlap zone formation (similar to pile group effect) (Muqtadir and Desai, 1986; Pressley and Poulos, 1986). Additionally, from a practical point of view, a minimum nail spacing is required to prevent potential for drilling into formerly placed nail elements.

5. Conclusions

Analytical and numerical analyses performed in the present study proved the effectiveness of the soil nailing method for the improvement of the ground conditions. The reinforcing effect was presented in terms of increased factor of safety as well as in therms of horizontal and lateral displacements. The numerical analyses revealed differences when performing factor of safety computations using LEM and FEM. This is due to assumed circular or wedge-shaped failure plain when applying method of slices, whereas for FEM the shear plane is more complex and non-circular. The geotechnical safety and overall stability of the three-storeyed building was proposed to be evaluated, based on the single wedge with planar failure surface. Applying such an approach proved a promising potential for using this principle analysis for an effective evaluation of shallow foundations constructed on weathered siltstone ground. Using both methods LEM and FEM is considered effective. However, assuming the most critical case scenario (FEM solution in this case) is desired. The case study was also investigated in terms of considering different retaining wall inclinations and soil reinforcing element patterns. As expected, the highest values of FS were reached for the smallest nail spacing and the highest gradient ratio.

Within this paper, severe scenarios such as earthquake, heavy rain, strong storm were not taken into consideration yet due to lack of advanced computation tools.

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Author contributions

Duc Van Bui: research idea, conception, data analysis and draft the article; Manh Van Nguyen, Piotr Osinski, Kennedy Chibuzor Onyelowe contribute to methodology and give a critical review during writing the first draft; Nhan Thi Pham, Trong Dang Nguyen, Somjai Yubonchit collected documents, data. All authors declare no conflict of interest.

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