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Parametric Study of the Effect of Ground Anchor on Deep Excavation Stability

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ABSTRACT Apartment construction is mostly carried out by including deep excavation works. However, excavation causes land instability; hence, the work needs to be done by a particular handler. In some cases, deep excavation is carried out on soft soil, which has a very high level of soil instability; therefore, a specific handling method such as ground anchor is required as an alternative. This study aims to conduct parametric research on the effect of using anchors on the stability of deep excavation. First, anchors of various slopes were modelled while varying the number of anchors up to four pieces. From the results of the study, the requirements representing the most efficient use of anchors were selected, and then various anchor bond lengths were modelled. Finally, the effect of applying various magnitudes of prestress forces to the anchor was determined. All of the models were examined to determine the influence on the stability of the deep excavation by observing the horizontal displacement and the forces that occur on the secant pile. From the analysis results, it can be concluded that the most effective slope angle is 0˚. The displacement and forces occurred in the secant piles on the use of two, three, or four anchors has not a significant difference. The application of a higher prestress force on the anchor would yield better results as long as it is not exceeding 200 kN. However, in the case of an apartment building's plans in Surabaya, the optimal anchor usage was found to be the use of two anchors with a 45˚ slope, 4.5 m for the first (A) and second (B) anchor bond lengths, 15 m free length anchor, 2.5 m vertical anchor distance, 1.2 m horizontal anchor distance, and the application of 200 kN prestress force.

KEYWORDS Deep Excavation; Ground Anchor; Secant Pile; Parametric Study; Prestresses

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1 INTRODUCTION

The need for excavation stability is an important factor in infrastructure development. There are many deep excavation methods, as explained by Wang et al. (2016). Incorrect implementation and handling of deep excavation can cause slope failure. Slope failure can cause losses such as damage to surrounding buildings, damage to heavy equipment, slowness of work processes, and even degradation of work safety. Therefore, reinforcement is required to avoid the damage caused by deep excavation instability.

There are several similar studies about soil nailing in deep excavations. Josifovski et al. (2012) reported that modelling deep excavations with multiple anchors by numerical analysis can help describe all the effects in the process of excavation in the presence of difficult materials and loading conditions. López et al. (2017) used a finite element method to estimate the earth pressures transferred to a pile, the moment and shear forces on the pile, and the anchor's stresses. Alsubal et al. (2017) also reported that angles of anchor give different results in deep excavation stability.

The supports of deep excavations have a very important role in nearby existing buildings (Zumrawi & El-Amin, 2016) and the construction itself. The stability of deep excavations can be handled and improved via various methods, one of which is to use a ground anchor. An overview by Budania & Arora (2016) stated that ground anchor has many advantages as regards construction, performance, and cost aspects. However, there are not many studies discussed the use of anchor in deep excavations strengthened by secant piles. Thus, this study aims to conduct a parametric study on the effect of using an anchor on the stability of deep excavations.

2 RESEARCH METHOD

The research is based on the development of an apartment building's plans in Surabaya. The analysis was started by modelling anchors of various slopes, with the number of anchors reaching four pieces. Based on the analysis results, the requirements representing the most efficient use of anchor were selected, and then various anchor bond lengths were modelled accordingly. Finally, the effects of providing various magnitudes of prestress force were determined. All the models were examined to determine the influence on the stability of the deep excavation by observing the horizontal displacement and the forces that occur in the secant pile. Moreover, the Plaxis v.8.6 software was used as a modelling tool, and all the soil layers behind the secant pile were assumed to be homogenous soil, according to the results of conducted investigation. The vertical and horizontal distances of each anchor were determined as 2.5 m and 1.2 m, respectively.

2.1 Free Length Anchor Design

The minimum unbound length (free length) of an anchor is 4.5 m for the wire type and 3 m for the tendon type. However, longer unbound lengths can be used for the following:

a) Determining the minimum bond length behind the potential critical failure line
b) Determining the bond zone for anchor
c) Ensuring the overall stability of the anchor
d) Accommodating anticipated long-term movement

Overall, the unbound length is H/5 or 1.5 m behind the critical failure potential line to accommodate the transfer of minor loads to the concrete column above the anchor in the bond zone. This is illustrated in Figure 1, where χ is equal to 1.5 m or 0.2 H (the highest value is selected).

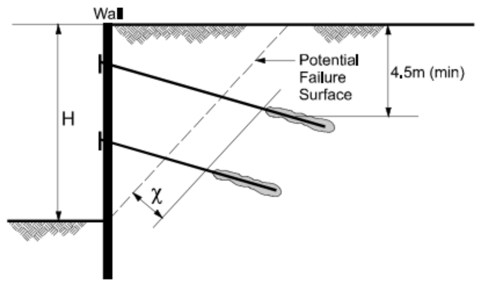

Figure 1. Free length design (FHWA,1999)

2.2 Planning the Bond Length in Anchor

The equation used in planning bond lengths on anchors is shown in Equation (1) (FHWA, 1999):

$$Bond\ length = \frac{T\ SF}{Estimated\ ultimate\ transfer\ load} \quad (1)$$

where T is the load that works on the anchor. In the analysis, determining the safety factor value (SF) is based on conditions in the field. In general, the SF value is taken as 2.

The bond length on anchors is generally 4.5 m to 12 m because lengths exceeding 12 m cannot be added unless a particular method that allows the transfer of loads from the base to the tip of the anchor is employed. Littlejohn (1981) suggests the use of Equation (2) for the design of bonded-length anchor on cohesionless soils.

$$T = K\pi DL\sigma'_v \tan\phi \quad (2)$$

where T is the stress on anchor, K is the soil pressure coefficient (1.4–2,3), D is the bond length diameter, L is the anchor bond length, σ'_v is the effective soil pressure, and ϕ is the soil friction angle.

Moreover, Littlejohn (1981) suggests the use of Equation (3) for the design of bonded-length anchor on cohesive soils.

$$T = \pi DL\alpha c_u \quad (3)$$

where T is the stress on anchor, D is the bond length diameter, L is the anchor bond length, α is the adhesion factor (0.45–0.6), and c_u is the soil cohesion parameter.

2.3 Modelling Input Parameters

Secondary data were used as a modelling input parameter. The modelling input parameters consist of soil input parameters (Table 1), secant pile (Table 2), anchor (Table 3), and bond length (Table 4). Excavation modelling in the field can be seen in Figure 2 and 3.

Table 1. Soil input parameter (Testana Engineering, 2015)

Depth (m)	Soil Type	N	c (kPa)	φ (°)	γ_{sat} (kN/m^3)	E (kPa)
0–14	*silty clay*	1	7	7	15.0	3,000
14–23	*clayey-sandy silt*	16	90	20	18.0	30,000
23–28	*silty sand*	31	20	30	19.5	30,000
28–40	*clayey silt*	21	100	8	18.5	30,000
40–60	*alternation sand and clay*	28	150	8	18.5	40,000

Table 2. Secant pile input parameter (Testana Engineering, 2015)

Parameter	Value	Units
Depth	12	m
Pole diameter	0.8	m
Area	0.50	m^2
Distance	1.2	m
I	0.02	m^4
E	23,500,000	kPa
EI	472,495.53	kNm^2/m
EA	11,812,388.38	kN/m
Concrete density	24	kN/m^3
W	12.06	kN/m^2
*EI**	393,746.28	kNm^2/m
*EA**	9,843,656.98	kN/m
w input	10.05	kN/m^2

Table 3. Anchor input parameter

Parameter	Value	Unit
n	4	piece
d	0.02	m
Sh	1.2	m
A	0.000565	m2
E	1.95E + 08	kPa
EA	110258.6	kN/m
F	625	kN

Table 4. Anchor bond length input parameter

Parameter	Value	Unit
d	0.2	m
A	0.03	m^2
E	23,500,000	kPa
EA	738,274.30	kN/m
s	1.20	m
*EA**	615,228.60	kN/m

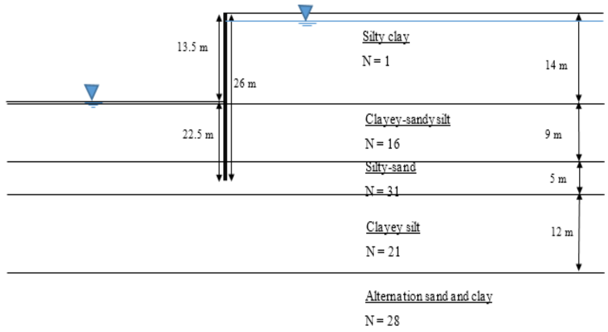

Figure 2. Field condition

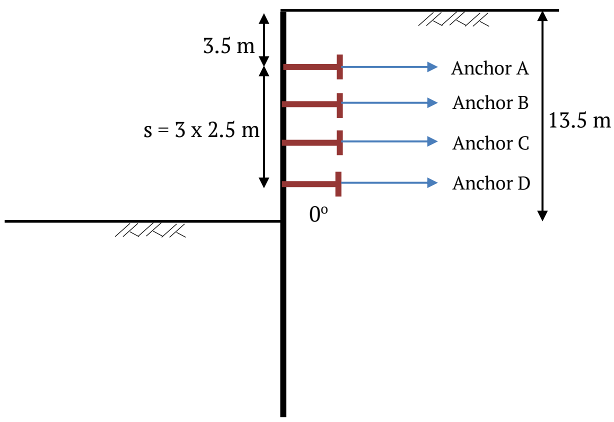

Figure 3. Naming and distance determination of anchor

3 RESULT AND DISCUSSION

3.1 Free Length Anchor Design

Based on the Federal Highway Administration (FHWA, 1999) standard, the minimum free length in anchor is 1.5 m or 0.2 times the secant pile height above the slope failure. Before the reinforcement, deep excavation modelling is conducted to determine the slope failure line. The modelling results can be seen in Figure 4.

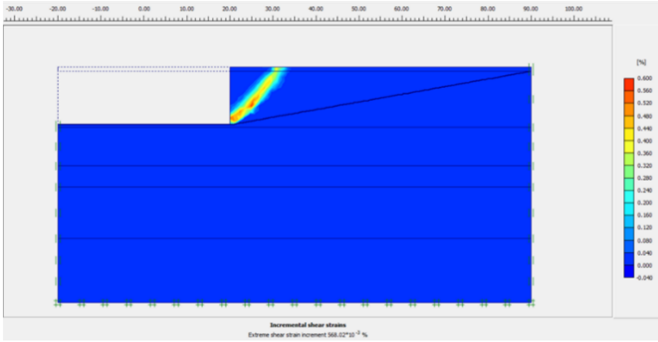

Figure 4. Shading of total displacement without reinforcement on deep excavation modelling

The slope failure line is denoted by yellow. The free length requirement at the angle of 0˚ anchor is 12 m plus 2.7 m (0.2 times the secant pile height from the surface of the soil excavation). Thus, the free length is determined to be as long as 15 m.

Gunawan, et al. (2017) reported that if the anchor length passes the effective value of the *L/d* range (400–650), the *SF* will not change significantly. However, in this case study, the free length needs to be more than 15 m so that the bond length will be built on hard soil.

3.2 The Anchor Slope Effect

3.2.1 Anchor Force

Based on the graph of the relationship between the value of *T* and the anchor slope, anchor A tends to feature an increase in stress with an increase in the anchor slope. For anchor B, the stress tends not to change with the increase in the anchor slope. Anchors C and D show tendencies of decrease in the anchor stress with the increase in the anchor slope. This shows that locating anchors above half the height of the secant pile, measured from the bottom surface of the excavated soil, tends to increase the T value due to the increase in the anchor slope. However, locating the anchors below half the height of the secant pile, measured from the bottom surface of the excavated soil, tends to decrease the T value due to an increase in the anchor slope. Figure 5 shows the relationship between the anchor stress (T) and the slope of the anchor considering four anchors.

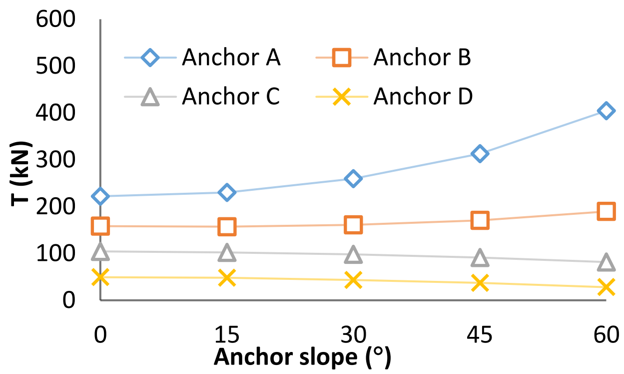

Figure 5. The relationship between the anchor stress (*T*) and the slope of the anchor considering four anchors

3.2.2 Secant Pile

The maximum horizontal displacement, moment, and shear in a secant pile show the same tendency, which is an increase in value with an increase in the anchor slope. The levels of increase in the maximum horizontal displacement, moment, and shear appear sharper after the anchor slope exceeds 45°. Thus, it can be concluded that an anchor slope exceeding 45° is not effective.

In the Figure 6 to 8, the effects of the increase in anchor slope on the maximum horizontal displacement, moment, and shear on the secant pile also show that the use of two to four anchors features results that are not much different; on the graph, the relationship lines corresponding to the usages of two to four anchors almost coincide. Thus, it can be concluded that the use of more than two anchors is not efficient.

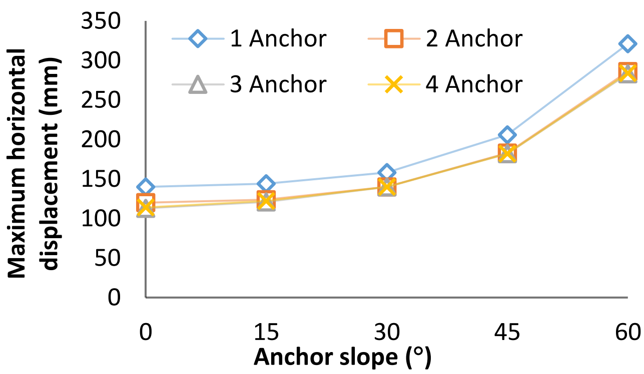

Figure 6. The relationship between the maximum horizontal displacement (δ_h) on the secant pile and the anchor slope

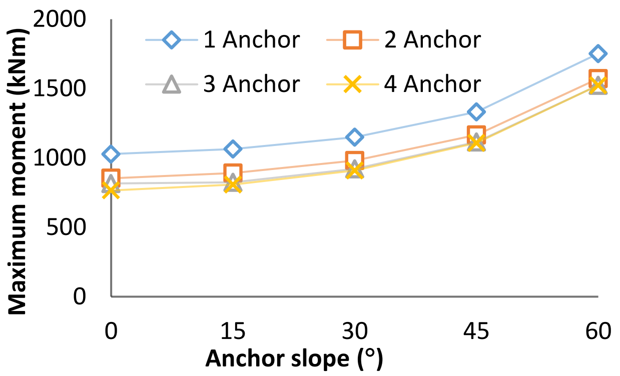

Figure 7. The relationship between the maximum moment on the secant pile and the anchor slope

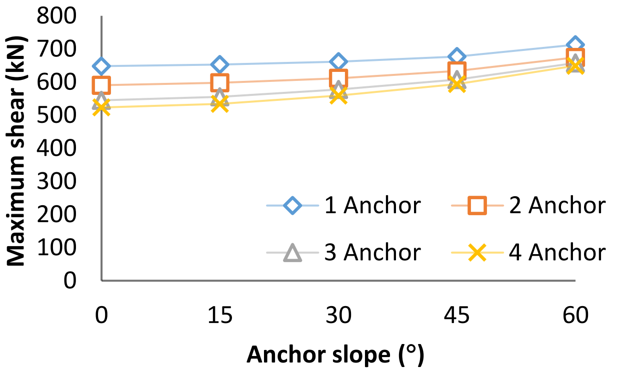

Figure 8. The relationship between the maximum shear of the secant pile and the anchor slope

3.2.3 Bond Length Analysis with the FHWA Method (1999)

Figure 9 shows the relationship between the bond length L_b and the anchor slope considering four anchors according to FHWA method (1999). From the obtained analysis results, the anchor slopes of 0° to 30° show the need for an anchor bond length of over 12 m. This is because the anchor bond length is planted on hard soil and thus is required to be very long. In this case, the 45° anchor slope is the minimum to be embedded at hard soil so that the bond length is relatively short. According to FHWA (1999), the recommended maximum bond length is 12 m.

3.2.4 Bond Length Analysis with Littlejohn Method (1981)

Figure 10 shows the relationship between the bond length L_b and the anchor slope considering four anchors according to Littlejohn method (1981). The required bond length (L_b) obtained by the analysis using the Littlejohn (1981) method is longer than that obtained by analysis done using the FHWA (1999) method. However, the relationships between the required bond length and the anchor slope show the same tendency.

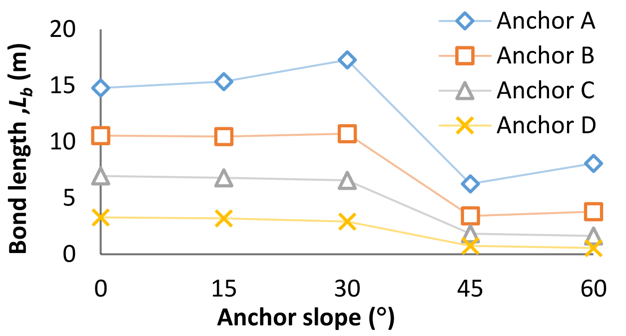

Figure 9. The relationship between the bond length L_b and the anchor slope considering four anchors based on FHWA (1999)

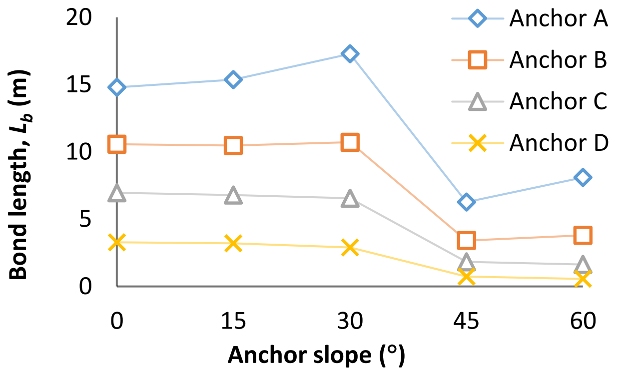

Figure 10. The relationship between the bond length L_b and the anchor slope considering four anchors according to Littlejohn (1981)

Angled slope analysis shows that the slope angle 0˚ is the most effective because the horizontal displacement and the forces acting on the secant pile are lowest; this also applies to forces acting on the anchor. Singh & Shrivastava (2017) reported the same result, that a 0˚-angled anchor is more efficient in providing stability to the slope. However, in this case study, the 0˚angled anchor requires a very long free length compared with that required by the 45˚ angled anchor due to the difference in soil layer. For this case study, the best anchor slope angle is 45˚.

In the analysis of the anchor slope, it can also be concluded that the use of more than two anchors does not give significantly different results (Figure 5 to Figure 7). The displacement and forces that occur in the secant piles on the use of two anchors are not much different from those that occur when three and four anchors are used.

3.3 Effect of Anchor Bond Length

The anchor bond length requirements were analyzed using two methods, which are the FHWA (1999) and Littlejohn (1981) methods. The results show that the required anchor bond length determined by the FHWA (1999) method is shorter. Thus, the anchor bond length obtained from calculations using the FHWA (1999) method is used as the minimum length of the anchor. For the use of one anchor, the anchor bond length is 9.4 m (anchor A), while for the use of two anchors, the bond lengths are 6.8 m (anchor A) and 4.2 m (anchor B).

The analysis results presented in Table 5 and Table 6 show that there are no significant changes in the horizontal displacement (δ_h), moments, and maximum shear forces. In addition, there is a condition where the anchor bond length penetrates a harder soil layer. However, the results show that even though the bond length penetrates a harder soil and is extended to 12 m, there is no significant effect on the horizontal displacement and forces on the secant pile. The anchor bond length reduction to a minimum limit of 4.5 m results in an increase in the horizontal displacement value and the forces on the secant pile even though slightly.

Table 5. The effect of adding a bonded-length anchor to secant pile using one anchor.

Information	Bond length on 1-anchor model (m) Anchor				δ_h	Max moment	Max shear
	A	B	C	D	mm	KNm/m	kN
Bond length on 1 layer	4.5	-	-	-	238	1170	571.0
	9.4	-	-	-	233	1150	568.0
	10.0	-	-	-	232	1150	568.0
	11.0	-	-	-	231	1150	568.0
	12.0	-	-	-	231	1150	569.7

Table 6. The effect of adding bonded-length anchor to secant pile using two anchors

Information	Bond length on 1 anchor model (m) Anchor				δ_h	Max moment	Max shear
	A	B	C	D	mm	KNm/m	kN
Bond length on 1 layer	4.5	4.2	-	-	212	1020	538
	6.8	4.2	-	-	210	1010	537
	9.0	6.0	-	-	210	1010	536
	12.0	8.0	-	-	209	1010	536
Bond length penetrates the harder layer	12.0	12.0	-	-	209	1010	535

3.4 The Effect of Prestress Force

Figure 11, 12, and 13 show the relationship between the prestress force and the maximum horizontal displacement, the maximum moment, and the maximum shear force, respectively. Two anchors usage provides a better result as regards the maximum moment, shear, and horizontal displacement of the secant pile than one anchor usage. However, applying a prestress force of more than 200 kN will increase the maximum moment, even though the maximum shear and horizontal displacement are decreasing. Therefore, combining two anchors usage and 200 kN of prestressing force is the best option to have an optimum result of the maximum moment, shear, and horizontal displacement of the secant pile.

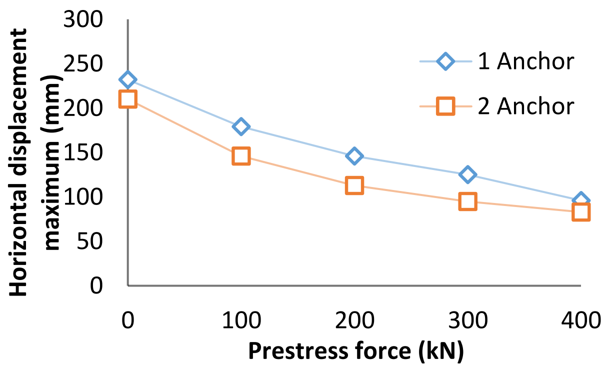

Figure 11. The relationship between the maximum horizontal displacement (δ_h) and the prestress force

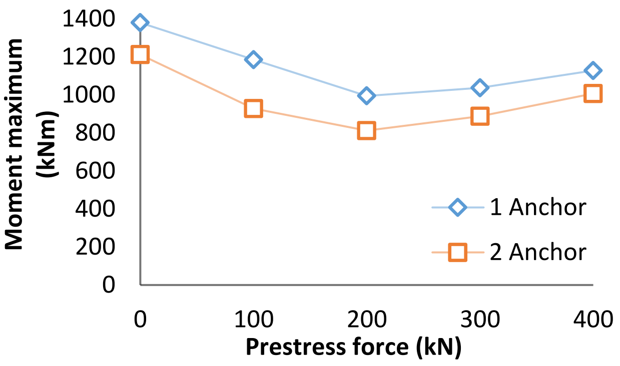

Figure 12. The relationship between the maximum moment and the prestress force.

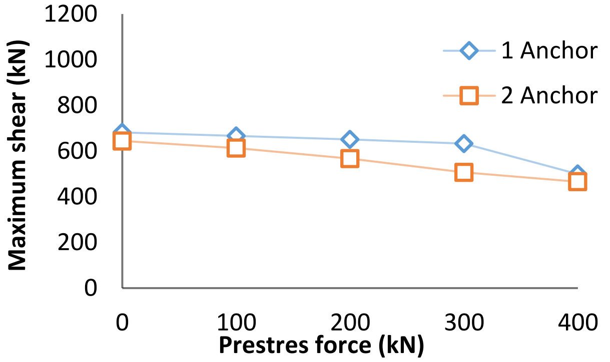

Figure 13. The relationship between the maximum shear and prestress force.

4 CONCLUSIONS

The analysis result shows that the slope angle 0° is the most effective due to the lowest horizontal displacement, the forces acting on the secant pile, and the forces acting on the anchor. In addition, the displacement and forces that occur in the secant piles on the use of two anchors are not much different from those that occur when three and four anchors are used. The application of a higher prestress force on the anchor would yield better results as regards the maximum shear and horizontal displacement of the secant pile. However, applying a prestress force exceeding 200 kN would increase the maximum moment of the secant pile.

In the case of an apartment building's plans in Surabaya, the optimal anchor usage was found to be the use of two anchors with a 45° slope, 4.5 m for the first (A) and second (B) anchor bond lengths, 15 m free length anchor, 2.5 m vertical anchor distance, 1.2 m horizontal anchor distance, and the application of 200 kN prestress force.

DISCLAIMER

The authors declare no conflict of interest.

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