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Pullout resistance of concrete anchor block embedded in cohesionless soil

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Abstract. The anchor block is a specially designed concrete member intended to withstand pullout or thrust forces from backfill material of an internally stabilized anchored earth retaining wall by passive resistance of soil in front of the block. This study presents small-scale laboratory experimental works to investigate the pullout capacity of a concrete anchor block embedded in air dry sand and located at different distances from yielding boundary wall. The experimental setup consists of a large tank made of fiberglass sheets and steel framing system. A series of tests was carried out in the tank to investigate the load-displacement behavior of anchor block. Experimental results are then compared with the theoretical approaches suggested by different researchers and codes. The appropriate placement of an anchor block and the passive resistance coefficient, which is multiplied by the passive resistance in front of the anchor block to obtain the pullout capacity of the anchor, were also studied.

Keywords: anchor block; retaining wall; passive resistance coefficient; pullout capacity; cohesionless soil

1. Introduction

Due to the development of materials and enhancement in technical understanding of geotechnical engineering, different types of soil retention systems have evolved over the last three to four decades (Khan and Sikder 2004). These systems may be classified into two groups, externally stabilized walls and internally stabilized walls. Typical examples of the externally stabilized wall are gravity wall, reinforced concrete cantilever wall, reinforced concrete counterfort wall, etc. Internally stabilized retaining walls are metal strip wall, geotextile reinforced wall, anchored earth wall, etc. These internally stabilized retaining walls comprise of horizontally laid reinforcements which carry most or all of the lateral earth pressure via soil-reinforcement interaction or via passive resistance from the anchor block. The anchor block is usually a cast-in-place or precast concrete member that may be square or rectangular in section with the necessary length to develop sufficient passive resistance for one or more anchor rods/cables attached along its length (Bowles 1997). Based on the orientation of anchors, the analysis of anchors can take one of two forms in general, namely vertical anchors or horizontal anchors.

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Although very recently some excellent researches were conducted on the uplift response of horizontal anchors by Niroumand and Kassim (2013), Keskin (2015), Demir and Ok (2015), Bhattacharya and Roy (2016) etc., this type of anchor is not the topic of interest here, and thus will not be reviewed. The vertical anchor is the subject of interest in this paper.

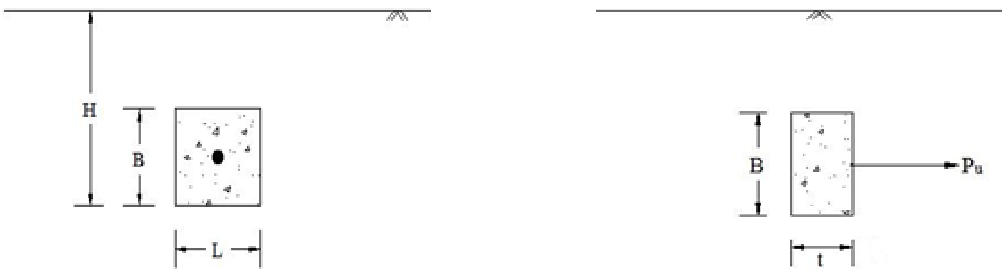
Literature reveals that many research studies have been conducted on the capacity of the vertical anchor plate. However, only a few studies were found for block anchor including that by Bowles (1997), Duncan and Mokwa (2001), and Naser (2006). Also, hardly any researches were conducted on the effect of anchor location from the retaining wall on pullout resistance. Consequently, the current study aims to investigate the pullout capacity of concrete anchor block located at different horizontal distances from yielding boundary wall using small scale laboratory models. Experimental results are then compared with the analytical and empirical approaches suggested by various researchers and codes.

2. Previous studies on vertical anchors

Sometimes it is not possible to represent actual field conditions perfectly in the laboratory. Despite this limitation, tests at the laboratory scale have the advantage to develop the understanding what actually takes place in the field. Moreover, laboratory studies can be used in conjunction with theoretical studies to formulate semi-empirical methods. Such experimental studies on the vertical anchors in the cohesionless soil are presented in Table 1. Illustrations of notation used in this table are presented in Fig. 1.

The theoretical methods of calculating pullout capacity of vertical anchor plate are commonly employed for anchor block also (Das 2007). Previous theoretical studies of anchors in the sand have typically utilized simple analytical approaches such as limiting equilibrium, cavity expansion and limit analysis. In the limit equilibrium method, a failure surface is assumed along with a distribution of stress along that surface. Equilibrium conditions are then considered for the failing soil mass, and an estimate of the collapse load is obtained (Merifield and Sloan 2006). These can be found in the works of Ovesen and Stromann (1972), Meyerhof (1973), Neely *et al*. (1973), Hanna *et al*. (1988), Murray and Geddes (1989), Basudhar and Singh (1994), Bowles (1997), Naser (2006) and Kame *et al*. (2012) etc. A summary of previous theoretical studies on vertical anchors is provided in Table 2.

For maximum efficiency, NAVFAC (1986) suggested that the anchor blocks should be placed outside the surface making an angle equal to the angle of friction of backfill soil, φ with the



(a) (b)

Fig. 1 Problem notation (a) Front view; (b) Side view of an anchor

Table 1 Laboratory model tests and field tests on vertical anchor in cohesionless soil (modified from Merifield and Sloan 2006)

Source	Type of testing	Anchor shape	Anchor size (mm)	Friction angle (°)	Anchor roughness (°)	H/B
Neely *et al*. (1973)	Chamber	Square; rectangular	50.8	38.5	21	1–5
Das and Seeley (1975)	Chamber	Square; circular	38–76	34	-	1–5
Akinmusuru (1978)	Chamber	Strip; rectangular; circular; *L*/*B* = 2, 10	50	24; 35	-	1–10
Ovesen (1981)	Centrifuge; Field	Square	20	29.5–37.7	-	1–3.39
Rowe and Devis (1982)	Sand chamber	Square; rectangular	51	32	-	1-8
Dickin and Leung (1983, 1985)	Centrifuge chamber	Square; rectangular; strip	25; 50	41	Polished, 29	1–8; 1–13
Hoshiya and Mandal (1984)	Sand chamber	Square; rectangular; *L*/*B* = 2, 4, 6	25.4	29.5	-	1–6
Murray and Geddes (1989)	Sand chamber	Square; rectangular; *L*/*B* = 1–10	50.8	43.6, dense	10.6	1–8
Dickin and King (1997)	Centrifuge	Rectangular	25	37.3-46.1	-	1-12
Duncan and Mokwa (2001)	Field	Rectangular block; *L*/*B* = 1.7	1100 × 1900 × 900	50	6	1
Naser (2006)	Chamber	Square block	150 × 150 × 150	43.5	7.3-11.2	2

horizontal (zone EBF of Fig. 2). The anchor blocks locating between φ line and Rankine's failure surface will generate partial passive resistance (zone EBC of Fig. 2). On the other hand, Bowles (1997) suggested locating the anchor block such that the Rankine's passive zone in front of the anchor block should be completely outside the Rankine's active zone behind the retaining wall (location *H* of Fig. 2).

BS 8006 (1995) recommends to use passive resistance coefficient while calculating the pullout resistance of an anchor block. This recommendation is based on the studies by Hansen (1966) that, the passive earth pressure against small structures is higher than those predicted by conventional earth pressure theories since the conditions at the ends of the structures are quite different from those at the center that has a significant influence on the passive resistance. According to Hansen (1966), the ultimate pullout resistance of vertical anchor should be multiplied by a coefficient (C) to account for the end effects given as

$$C = 1 + \left(K_p - K_a\right)^{0.67}\left[1.1E^4 + \frac{1.6F}{1 + 5\left(\frac{L}{B}\right)} + \frac{0.4\left(K_p - K_a\right)E^3F^2}{1 + 0.05\left(\frac{L}{B}\right)}\right] \quad (1)$$

Where, K_p and K_a are the coefficients of passive and active earth pressure respectively,

Table 2 Theoretical studies on vertical anchors in cohesionless soil (modified from Merifield and Sloan 2006)

Source	Analysis method	Anchor shape	Anchor roughness	Friction angle (°)	H/B
Ovesen and Stromann (1972)	Limit equilibrium – semi-analytical	Strip; rectangular	Rough	All	All
Meyerhof (1973)	Limit equilibrium – semi-analytical	Strip	-	All	All
Neely *et al*. (1973)	Limit equilibrium and method of characteristics	Strip	Rough	30-45	1-5.5
Rowe and Davis (1982)	Elastoplastic finite element	Strip	Smooth	0–45	1–8
Hanna *et al*. (1988)	Limit equilibrium	Strip; inclined	-	All	All
Murray and Geddes (1989)	Limit analysis – upper bound	Strip; inclined	Smooth; rough	43.6	1–8
Basudhar and Singh (1994)	Limit analysis – lower bound	Strip	Rough; smooth	32; 35; 38	1–5
Ghaly (1997)	Empirical	Strip; circular rectangular;	-	34-38.5	1-5
Bowles (1997)	Limit equilibrium	Strip	-	All	-
Naser (2006)	Limit equilibrium with shape correction	Rectangular	Rough	All	-
Merifield and Sloan (2006)	Limit analysis – upper and lower bound	Strip	Rough	20-40	1-10
Kame *et al*. (2012)	Limit equilibrium	Strip	Rough	All	1

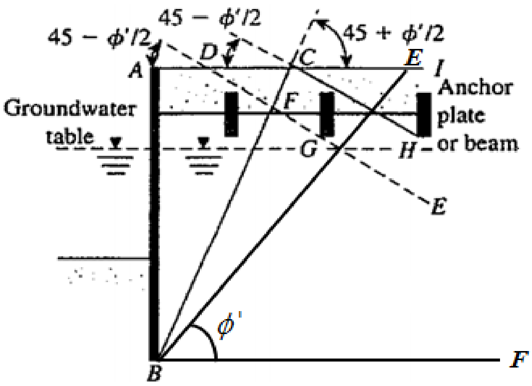


Fig. 2 Effect of placement of anchors on pullout resistance (adapted from Das 2007)

$E = 1\text{-}B/H$ and $F = 1-(L/S^{'})^2$, and $S^{'}$ is the center-to-center distance between two anchors. The anchor block geometry used in Eq. (1) can be found in Fig. 1. According to the BS 8006 (1995), the horizontal pullout resistance of an anchor block is 4 times the passive pressure force acting on anchor block (ignoring the insignificant amount of resistance offered by rebar), i.e., passive resistance coefficient, C = 4 is suggested. Naser (2006) also utilized the passive resistance coefficient from Eq. (1) to estimate pullout capacity of an anchor block.

3. Experimental investigation

3.1 Material property

Three types of air dry sands were used in this research work. Various tests were made to characterize these sands according to the respective ASTM Standards. The properties of the sand used in this investigation are presented in Table 3. According to Unified Soil Classification System (USCS), these sands are categorized as poorly graded sand (SP). This research used pluviation method to fill up the pullout box. In this method, the unit weight of sand deposited by sand screener/ spreader as shown in Fig. 3 depends on the size of the aperture through which sand falls and the height of fall. The sand spreader was calibrated by determining the unit weight of sand for different height of fall before the test. The optimum height of fall, corresponding to the maximum unit weight of sand, was selected as 850 to 900 mm depending on the types of sand and presented in Table 4. To obtain uniform, homogenous, isotropic and reproducible sand deposits in the pullout box, this optimum height of fall was always maintained during the deposition of sand by changing the height of sand screener gradually in the upward direction. The corresponding unit weights for three types of sands were determined, which were used to calculate the respective relative densities of sands (Table 3). These relative densities were maintained during the direct shear test to obtain the angle of internal friction for the sands used in the study.

A concrete block of dimension 150 mm × 150 mm × 75 mm was used in this study. The compressive strength of concrete was tested for 7 days and 28 days and found to be as 13 MPa and 17 MPa respectively (ASTM C39). Three GI wires of diameter 1.8 mm were used as reinforcing

Table 3 Properties of the sands used in this study

Property	ASTM Standard	Sample-1	Sample-2	Sample-3
Fineness modulus (FM)*	C 125	0.73	1.5	2.5
Specific gravity	D 854	2.7	2.68	2.62
Effective grain size, D_{10} (mm)	D 2487	0.075	0.170	0.180
Uniformity coefficient, C_u	D 2487	2.67	2.12	4.65
Coefficient of curvature, C_c	D 2487	1.31	0.86	1.00
% Fines (passing #200 sieve)	D 2487	9	2	1
Maximum unit weight, $\gamma_{d,\max}$ (kN/m^3)	D 4253	15.98	16.74	18.10
Minimum unit weight, $\gamma_{d,\min}$ (kN/m^3)	D 4254	12.43	13.33	14.79
Unit weight of sand, $\gamma_{d,\text{box}}$ (kN/m^3) **		14.74	15.62	17.51
Relative density, D_r (%)		70	72	85
Angle of internal friction, φ°	D 3080	37.2	43.9	44.9

* FM is defined as one hundredth of the sum of cumulative percentages of retained on a series of specified sieves in sieve analysis. The larger the FM, the larger will be the soil particle.
** The unit weight of sand bed after the application of pluviation method in the pullout test box.

Table 4 Optimum height of fall of sand to achieve maximum unit weight by pluviation method

Soil Type	Height of fall (optimum) at maximum unit weight, mm	Maximum unit weight at optimum height of fall, kN/m^3	Relative density, D_r (%)
Sample-1	850	14.74	70
Sample-2	900	15.62	72
Sample-3	850	17.51	85

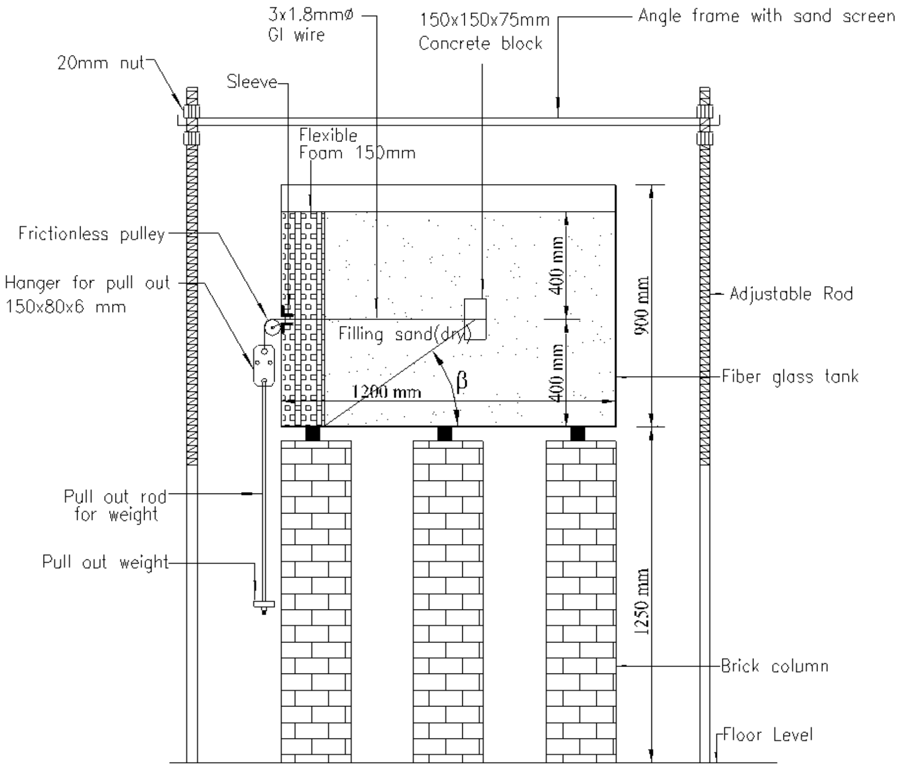


Fig. 3 Schematic diagram of the pullout test setup

materials for pulling the concrete block. Average yield or proof strength and Young's modulus were found to be 350 MPa and 201000 MPa respectively from tension test of wire (ASTM A421M).

3.2 Model preparation

The experimental setup mainly consists of a model pullout box made with fiberglass sheet, a sand screener used as a sand spreader, a brick platform to place the box on it, a pulling rod to hold the loading disk, a frictionless smooth roller/pulley mounted on the front side of the box in order to smooth rolling of reinforcing GI wire during the application of pulling force on it as shown in Fig. 3. The pullout box designed and constructed by connecting some frames to each other by providing necessary bolting and welding. The 900 mm deep box has an inside dimension of

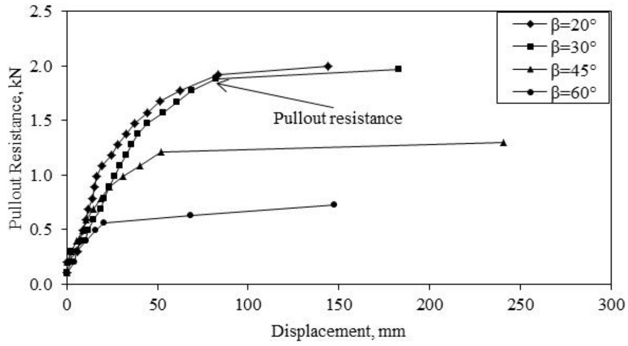
1200 mm × 900 mm. The longer two sides and shorter front sides were bounded by 6 mm thick transparent fiberglass sheets whereas 3 mm thick MS sheets were used on the shorter back sides of the box. The sleeve plates of 50 mm in width were used to minimize the lateral stress transfer to the rigid front wall of the pullout box. The sleeves were located at 400 mm height above from the base of the box. The glass sheet was supported on flat sides of mild steel angle frame and screwed to the frame to prevent any damage to glass sheet walls during loading. Along the edge of the glass sheets, silicon rubber was pasted between the edges to have a leak proof box. An elevated brick platform of height 1250 mm from the floor level was provided at the bottom of the box to rest on it. The platform facilitates free space for vertical displacement of pulling rod during the holding of loading weight disks on it. A smooth, frictionless steel roller was mounted on pullout box frame in the shorter front side. The roller allows a frictionless movement of reinforcing GI wire over it while applying the pulling force. A pullout rod made of 16 mm diameter mild steel bar bend at the top as a hook in order to attach to the mild steel hanger to grip the GI wire. Bottom of the pulling rod was plugged with a steel plate to hold the pullout force from slotted loading weight disk. A soft yielding boundary was provided using flexible foam at the front wall which facilitates the anchor block to displace towards the wall while pulling. Thus, it represents the field condition by ensuring the full mobilization of passive earth pressure in front of the block and active earth pressure behind the yielding boundary wall.

3.3 Pullout testing

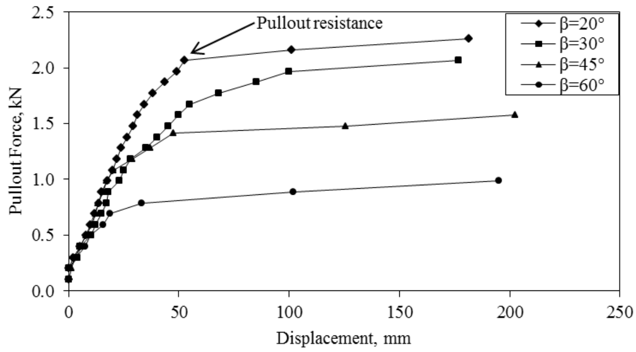
In this study, the placement or location of the anchor block was defined by an angle β with the horizontal at the toe of the yielding boundary wall as shown in Fig. 3. With the increase of horizontal distance of an anchor block from yielding boundary wall, angle β decreases. That means anchor block is placed far away from the yielding boundary wall for $\beta = 20°$ than for $\beta = 30°$. The pullout box was filled with sand by pluviation method up to the sleeve level. The anchor block was then placed at the mid-height level of the sand backfill with $\beta = 20°$. The anchor block was then buried with sand backfill to ensure an embedment depth (H in Fig. 1) of 475 mm. A series of slotted circular weight disks of 10 kg per disk were mounted on pullout rod to apply a pullout force through the frictionless pulley. Weights were placed on the pan of pullout rod to pull the anchor block horizontally which induces horizontal movement of the block. Thus, the pullout rod moves vertically downward due to the horizontal movement of anchor block. This vertical displacement of pullout rod for each increment of weight disk was measured by placing a steel measuring scale with a precision of 0.5 mm between the pan of pullout rod and floor level. The geometry (length, diameter) and material property (Young's Modulus) of GI wire and pullout rod were used to calculate elongation due to loading at each load increment and deducted from the observed displacement to obtain the actual horizontal displacement of anchor block. Weights were gradually increased to monitor the ultimate pullout force which was associated with sudden large horizontal displacement of block anchor. Failure revealed itself by a bulged area on the surface of the sand located on the passive side, and by a depression on the active side of the block. This process was continued for each type of sand for other locations, e.g., $\beta = 30°, 45°$, and $60°$; to investigate the effect of placement of anchor block on their capacity of mobilizing passive resistance. The embedment depth of anchor block was kept 475 mm in each case. Each test was performed for three times to obtain average load-displacement curve, i.e., total thirty six tests were carried out in this study for four different locations of anchor from yielding boundary wall in each type of sand.

4. Results and discussions

The variation of average pullout forces with horizontal displacement for the different location of anchor block from yielding boundary is presented in Fig. 4. In this study, the load-displacement curves do not show any peak; rather the pullout force is increasing very gradually after plastic yielding. Therefore, maximum pullout resistance (PR) is defined by adopting failure points, as shown in Fig. 4, after which the load-displacement diagrams become practically linear, i.e., at the



(a)



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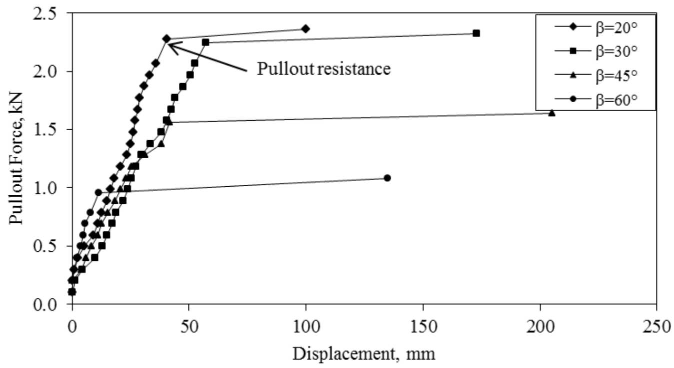

(c)

Fig. 4 Variation of pullout forces of the anchor block with horizontal displacement: (a) sample-1 with φ = 37.2°; (b) sample-2 with φ = 43.9°; and (c) sample-3 with φ = 44.9°

initiation of a large displacement of an anchor block (Neely *et al*. 1973, Das 1990). This method was also utilized by Dickin and King (1997) and Ghaly (1997), and they found more consistent results between theoretical studies and experimental studies than other alternative methods.

Table 5 and Fig. 5 represent the variation of pullout resistance (P_R) with the distances of the anchor block from yielding boundary wall for three types of sands used in this study. Here, the different types of sands used in this study are represented by their respective angle of internal friction ($\varphi°$), since the determination of pullout resistance and passive resistance coefficient from literature requires the angle of internal friction only as a soil property of cohesionless soil. As expected, the pullout resistance of the anchor block was observed to increase with the increase of anchor distance (or, with the decrease of β) from the yielding boundary wall, as shown in Fig. 5. The upper portion of each curve is somewhat flat (β = 20° to 30° in Fig. 5), followed by a linear relationship for pullout resistance with β having a steeper slope (β = 30° to 60° in Fig. 5). This phenomenon can be explained by referring to Fig. 2. If the anchor is placed at sufficient distance from retaining wall (at *H* in Fig. 2), full passive resistance is expected to mobilize since necessary space is available for the development of full passive failure wedge in front of the anchor block. However, the pullout resistance is expected to remain same even after placing the anchor far distant than the location *H* in Fig. 2 from the retaining wall, as the geometry of the passive failure wedge should remain same for similar soil condition. Thus, due to the full development of nearly same sized passive wedge at β = 20° and 30° for this study, the upper portion of each curve in Fig. 5 was found to be somewhat flat or, constant pullout resistance with β. As the distance of an anchor from retaining wall decreases, the size of the passive failure wedge also decreases accordingly due to the intersection of passive failure wedge in front of the block and the active failure wedge behind the wall as shown in Fig. 2 corresponding to location *G*. Therefore, a steeper

Table 5 Pullout resistance of the anchor block at different locations from yielding boundary wall for three types of sands used in this study

Soil property	Pullout resistance, P_R (kN)			
$\varphi°$	β = 20°	β = 30°	β = 45°	β = 60°
37.2 (Sample-1)	1.92	1.88	1.22	0.56
43.9 (Sample-2)	2.06	1.97	1.41	0.79
44.9 (Sample-3)	2.28	2.24	1.56	0.95

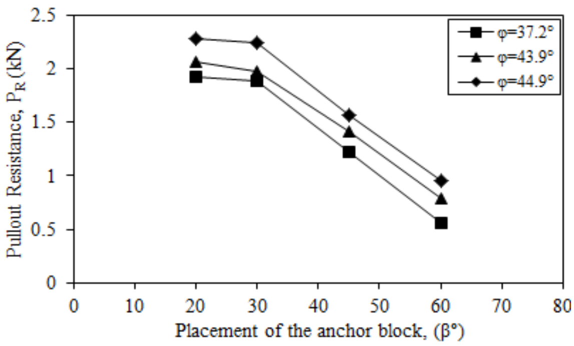

Fig. 5 Variation of pullout resistance with different anchor locations from yielding boundary wall for three types of sands used in this study

linear relationship between pullout resistance and anchor distance is obtained for β = 30° to 60° in Fig. 5 due to the partial development of passive failure wedge.

According to the NAVFAC (1986) guideline, β should be less than or equal to φ = 37.2°, 43.9° and 44.9° for sample-1, 2 and 3 respectively to ensure the full mobilization of passive resistance in front of the anchor block. However, this investigation indicates that full passive resistance might not develop even after placing the anchor block just outside the surface making an angle equal to the angle of friction of backfill soil, φ with the horizontal (Fig. 2). For instance, if an anchor is placed at $\beta = \varphi$ = 44.9° for sample-3 following the NAVFAC (1986) guidelines, the experiment resulted the approximate capacity as 1.56 kN (from Table 5) that is 30% smaller than the full passive resistance of 2.24 kN at β = 30°. On the other hand, Bowles (1997) suggested placing the anchor in such a way so that Rankine's active zone behind the retaining wall and the passive zone in front of the anchor block do not intersect to ensure full mobilization of passive resistance. To satisfy this condition, authors found from some paper works that the β should be less than 20° for all types of sands used in this study to achieve full passive resistance, which is also confirmed by the present experimental studies.

For comparison, pullout capacity were calculated using other theoretical approaches, e.g., Ovesen and Stromann (1972), BS 8006 (1995), Ghaly (1997), Bowles (1997), and Naser (2006) and the percentage errors of these methods with respect to the experimental results for β = 20° are presented in Table 6. These theoretical approaches estimate the pullout resistance for full mobilization of passive resistance in front of the anchor block. Therefore, experimental results for β = 20° were chosen for comparison due to the assumption that the passive resistance mobilized completely at this location. Rankine's lateral earth pressure theory was used while calculating the pullout capacity from theoretical approaches.

Ovesen and Stromann (1972) overestimated the test results in all three cases here. They considered friction between wall and soil during upward movement of the passive wedge, which in turn contributes favorably in pullout capacity. However, anchor block moves together with the passive wedge resulting in no shear displacement between the wall and passive wedge (Duncan and Mokwa 2001). Thus, the test results are smaller than their predictions for anchor block. BS 8006 (1995) also overestimated test results in all cases significantly. Both BS 8006 (1995) and Naser (2006) use passive resistance coefficient to estimate the pullout capacity of anchor block. Detailed discussion on passive resistance coefficient is provided in the later parts of this section. Ghaly's (1997) empirical equation predicted test results more accurately than other methods. He used the results of 104 laboratory tests, 15 centrifugal tests, and 9 field tests to propose this empirical correlation, where unit weight and internal friction angle of soil ranged from 14 to 16 kN/m^3 and 34° to 38.5° respectively. It is expected that more deviation from the range of test parameters used to derive the empirical correlation causes more errors. This is probably the reason

Table 6 Comparison of theoretical predictions of pullout capacity with experimental results for β = 20°

Exp. results	Ovesen and Stromann (1972)		BS 8006 (1995)		Ghaly (1997)		Bowles (1997)		Naser (2006)	
P_R (kN)	P_R (kN)	% error	P_R (kN)	% error	P_R (kN)	% error	P_R (kN)	% error	P_R (kN)	% error
1.92	2.2	15.8	2.2	15.8	2.1	10.5	0.6	-68.4	1.8	-5.3
2.06	3.1	47.6	3.1	47.6	1.8	-14.3	0.9	-57.1	3.6	71.4
2.28	3.5	52.2	3.6	56.5	1.9	-17.4	1.0	-56.5	4.4	91.3

for highest error corresponding to the test results of sample-3, where unit weight and internal friction angle of soil were 17.51 kN/m^3 and 44.9° respectively. However, the proximity of the laboratory test results of this study with the predicted results from his equation is expected, as he used many laboratory test results (total 104) to derive the empirical equation, which in turn validates the test results of the present study as well. In other circumstances, Bowles (1997) method underestimated all the test results significantly. He used conventional earth pressure theories assuming implicitly that the conditions at all cross sections along the length of a structure are the same which is valid for strip anchor, and ignored the influence of the different conditions at the ends of a small structure (e.g., anchor block) which contributes greatly to pullout resistance of anchor.

The passive resistance coefficient (C) is presented in Table 7 and Fig. 6 at different locations of the anchor block from yielding boundary wall. It is defined as the ratio of pullout resistance of anchor block (from Table 5) and the corresponding passive resistance acting in front of the anchor block. Rankine's earth pressure theory was used to determine the passive resistance. Due to the partial mobilization of passive resistance at β = 30° to 60°, *C* decreases with the increase of β for a particular type of sand. The increment of coefficient *C* is insignificant when the anchor block is placed at an angle β = 20° from β = 30° as passive resistance is assumed to be fully mobilized for both cases. BS 8006 (1995) suggested using *C* = 4 to calculate the pullout capacity of an anchor irrespective of soil properties. In contrast, *C* derived from Hansen's (1966) formula (Eq. (1)) varies with the angle of internal friction, that is depicted along with experimental results for β = 20° in Fig. 7. Present experimental investigation shows that *C* is less than 4 for all types of samples used in this study (Fig. 7).

Table 7 Passive resistance coefficient (*C*) at different locations of the anchor block for three types of sands used in this study

Soil property	Passive resistance coefficient, *C*			
φ°	β = 20°	β = 30°	β = 45°	β = 60°
37.2 (Sample-1)	3.48	3.41	2.21	1.01
43.9 (Sample-2)	2.59	2.47	1.77	0.99
44.9 (Sample-3)	2.43	2.39	1.66	1.01

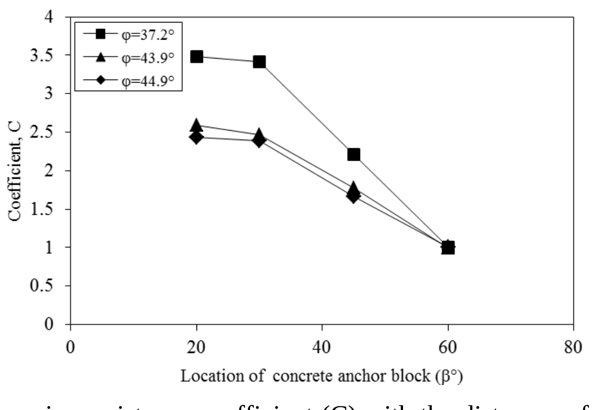

Fig. 6 Variation of passive resistance coefficient (C) with the distances of anchor block from yielding boundary wall for three types of sands used in this study

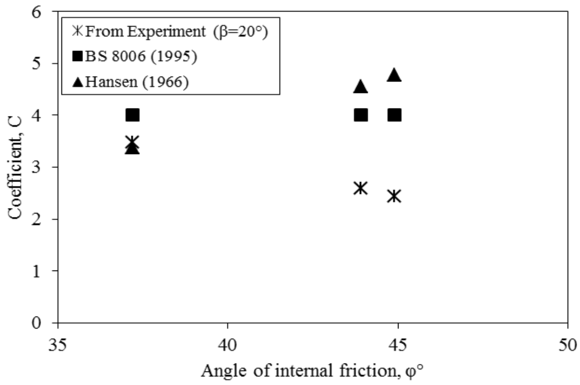

Fig. 7 Comparison of passive resistance coefficient (C) obtained from analytical approach and code with the experimental results for different types of sands used in this study

Fig. 7 also indicates that the passive resistance coefficient, *C* calculated from Eq. (1) is very close to the experimental result for the sands of φ = 37.2° and higher for φ = 43.9° and φ = 44.9°. As the angle of internal friction of sand increases the value of coefficient *C* from Eq. (1) also increases whereas the investigation shows the decrease of *C* with the increase of angle of internal friction. This is probably due to the fact that Eq. (1) was derived by assuming a simplified geometry of passive failure wedge that moves up due to the pullout force exerted from retaining wall via rebar. However, the actual failure wedge might not be in regular shape, and the experimental studies by Hueckel (1957) showed that the size of the actual passive failure wedge is smaller than the Rankine's passive failure wedge in front of the anchor for dense sand. The higher difference in wedge size occurs for higher friction angle of soil. Thus, the equilibrium of assumed higher sized passive wedge yields greater results for higher friction angle of soil. Since the passive resistance coefficient from Eq. (1) is also utilized by Naser (2006) to calculate the pullout capacity of an anchor block, his method also overestimated the experimental studies for φ = 43.9° and φ = 44.9°.

5. Conclusions

Based on the experimental investigations and test results, the following conclusions are made.

- After the full development of passive failure wedge in front of an anchor, the increase of anchor distance from retaining wall will not provide additional pullout resistance. However, a linear reduction in pullout capacity is observed as the anchor distance decreases from yielding boundary wall due to the intersection between active zone behind the wall and passive zone in front of the anchor.
- Bowles's (1997) guideline regarding anchor placement can be considered as safe or conservative than the NAVFAC (1986) method to ensure full mobilization of passive resistance.
- Ghaly's (1997) empirical method was found to be more consistent with the experimental studies than other methods. Due to its simplicity, it can be used for rough estimation of pullout capacity of an anchor block.
- From the present study, Passive resistance coefficient (*C*) was observed to be less than 4.

Thus, lower *C* value may be used to ensure a safe design.

Sufficient field observations are required to develop confidence among the users about the suitability of different methods mentioned in the literature. The authors hope that this paper will be useful to all those dealing with civil engineering projects and research works on the anchored retaining wall. This article will also be helpful to those who are involved in the development of standards for the determination of horizontal pullout capacity of an anchor block.

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