



Pullout Capacity of Small-Scale Jack-Like Ground Anchor in Sand with Various Relative Density

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Abstract

The pullout behavior of ground anchors in sand is governed by inter-particle friction and mechanical interlocking; however, conventional designs often fail to fully mobilize the surrounding failure zone, resulting in limited uplift capacity. To address this limitation, a jack-like ground anchor was developed, incorporating mechanically expandable wings to increase the soil-anchor contact area and enhance shear resistance. Laboratory pullout tests were conducted in a cylindrical steel tank to investigate the influence of relative density ($D_r = 27\%, 50\%, 80\%$), embedment depth ($H = 0.50-1.00$ m), and wing opening angle ($0^\circ-75^\circ$) on the anchor's performance. Test results interpreted using the Mazurkiewicz method revealed that increasing wing expansion and soil density substantially improved pullout resistance. In medium-dense sand, capacity increased by up to 250%, and in dense sand, up to 220%, depending on embedment depth. At the deepest embedment and densest condition, capacity increased from 6 kN (closed) to 16 kN (fully opened). These findings confirm that integrating geometric adaptability with soil density optimization significantly enhances uplift efficiency, providing a novel and practical solution for improving anchor performance in granular soils.

Keywords: Embedment Ratio; Granular Soils; Jack-Like Ground Anchor; Pullout Capacity.

1. Introduction

Ground anchors are crucial components in geotechnical practice. They are designed to transfer tensile forces from structures to soil with the help of adhesion and friction mechanisms. Retaining structures, slope stabilizations, tower foundations, and offshore applications make these systems necessary when structures are experiencing instability such as uplift forces and in need of lateral support [1-3]. Soil characteristics, embedment depth, and anchor configuration are some parameters to determine the ground anchors' pullout capacity. In the context of granular soils, load transfer is mainly altered by internal friction and mechanical interlocking between soil particles, where the role of cohesion gets overlooked often [2, 4, 5].

The embedment ratio is a measurement used many times to measure a ground anchor's performance; it is interpreted as the ratio of the anchor embedment depth (H) to the anchor width or diameter (B). Embedment ratio is a dimensionless parameter that measures the effectiveness of interaction between soil and anchor; this measurement has been validated to noticeably affect the pullout capacity. In many cases, the embedment ratio enhances pullout capacity until a certain depth is reached; this means the greater the penetration, the greater the decline of pullout capacity will happen [6, 7]. Other than embedment depth, the shape and geometry of the anchor influence stress distribution; this parameter also

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affects the formation of failure zones in soil surrounding the anchor. Different designs, such as circular plates, square plates, and strip configuration, contribute to giving various pullout reactions related to variations in contact area and stress concentration pattern [1, 8-10].

The evaluation of anchor pullout capacity usually utilizes three complementary approaches: experimental testing, numerical modeling, and analytical methods. The experimental approach, whether conducted at laboratory scale or full scale, provides direct insight into the influence of soil conditions, embedment depth, and anchor geometry by observing load–displacement responses [2, 9]. Numerical analysis, using finite element methods and limit equilibrium analysis, can simulate stress distribution and failure patterns under various soil conditions and has shown consistent results compared to empirical methods [11–15]. Analytical methods, based on theoretical approaches, are still effective for determining ultimate capacity, although calibration with field data is required for site-specific conditions [3, 12, 13].

Previous studies have examined various anchor configurations to improve performance and simplify installation while maintaining adequate bearing capacity. Traditional anchor geometries, such as circular plate anchors, square plate anchors, strip anchors, and helical anchors, each have their own limitations and exhibit unique behavior under different soil conditions [1, 9, 16, 17]. The pullout capacity of anchors in sand depends on factors such as soil density, embedment depth, anchor size, inclination angle, and anchor shape [9, 18–20]. However, these conventional shapes have practical limitations; most require pre-boring of the soil before installation, followed by grouting or backfilling, which makes field operations difficult, particularly in saturated, granular, or cohesive soils [3, 21]. These installation challenges have led to the development of new anchor designs that can be installed more quickly while maintaining adequate pullout capacity.

Some researchers already developed winged anchor designs to improve pullout capacity by increasing the soil-anchor interaction area, e.g., expanded ground anchors, folding anchors, and double-folded anchors [21-23]. The prototypes of three steel boxes with various sizes of expandable anchors have been studied in dense sand to mitigate heaving in expansive soils, showing a significant decrease of swelling effects [22]. Folding anchor designs were tested in cohesive soils, showing that the pullout capacity increases in a deeper embedment depth with a significant bearing capacity improvement [21]. A thorough study of double-fold anchors showed that the design developed pullout capacity because the soil resistance improvement led to higher tensile resistance [23]. However, the problem in installation still occurs in these designs. The idea of a simpler anchor design that can be installed at a designated depth and maintain adequate pullout capacity is significantly needed.

The jack-like anchor is an innovative ground anchoring system inspired by the working mechanism of an automotive scissor jack, as illustrated in Figure 1-a. The anchor is equipped with folding wings that remain closed during installation and are mechanically expanded after reaching the target embedment depth by applying torque to the central rod. Unlike conventional anchors, this post-installation expansion increases the effective contact area between the anchor and the surrounding soil, thereby enhancing mobilized shear resistance and pullout capacity. A sphere-shaped head is incorporated to facilitate penetration and reduce soil resistance during installation. Once the anchor reaches the designated depth, mechanical rotation activates the expansion of the folding wings, analogous to the operation of a scissor jack (Figures 1-b and 1-c). The expanded configuration enlarges the frictional zone at the soil–anchor interface and improves load transfer efficiency between the anchor and the surrounding soil.

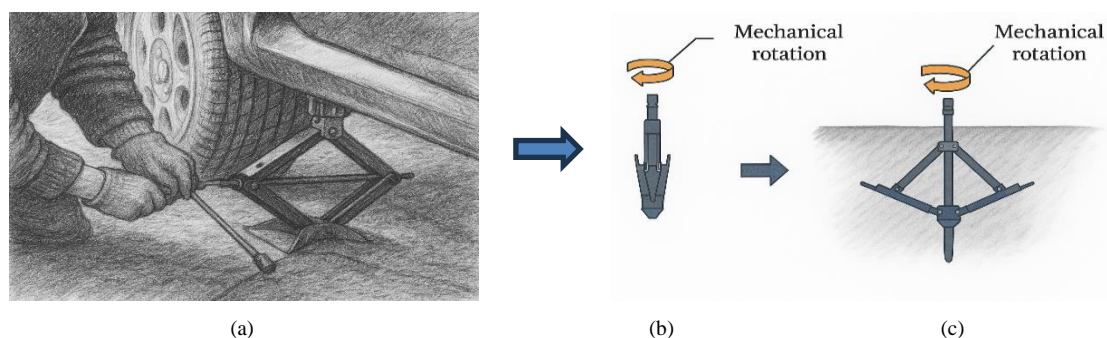


Figure 1. (a) Concept of the jack-like ground anchor; (b) automotive scissor jack mechanism; (c) jack-like ground anchor embedded in sand

The geometric flexibility of the jack-like anchors offers possible advantages. The angle of wing opening can be adjusted mechanically, which facilitates flexibility for various soil conditions and project conditions. Furthermore, it also allows the anchor to be used in different soil densities, from loose to dense sand, and at different embedment depths. The combination of an expanded wing mechanism and conical head design is determined to improve the pullout capacity and installation reliability compared to conventional fixed-shaped anchors. However, the performance of jack-like anchors in granular soils has not been studied. The influence of relative density, embedment depth, and wing opening angle on pullout capacity is not well examined.

However, the behavior of jack-like anchors in granular soils has not been experimentally studied. In particular, the combined effects of relative density, embedment depth, and wing opening angle on pullout capacity remain unclear. This study aims to fill this gap through a series of controlled laboratory experiments to evaluate the performance of jack-like anchors in sand. The objectives are to (i) quantify the influence of geometric and soil parameters on pullout capacity, (ii) identify optimal configurations for maximum uplift resistance, and (iii) provide practical insights for design and implementation.

2. Materials and Methods

This experimental investigation aimed to evaluate how the pullout behavior of a jack-like ground anchor is influenced by relative density (D_r), wing opening angle (A), and embedment depth (H). The laboratory testing was conducted using a small-scale physical model inside a cylindrical steel tank. A total of 45 test configurations, representing all combinations of the three variables, were performed to ensure data reliability and reproducibility. The jack-like ground anchor prototype, inspired by the mechanical concept of an automotive scissor jack, was fabricated from high-grade steel to ensure stiffness and durability during loading. Pullout capacity tests were conducted in a cylindrical steel container with an internal diameter of 1.2 m and a height of 1.2 m. The sand inside the tank was prepared to meet the target relative densities and prescribed wing opening angles. The prototype consisted of a steel rod (12 mm in diameter), two wings (32 mm wide, 4 mm thick), and a conical head (36 mm diameter) (see Figure 3).

Tests were performed at embedment depths of 0.50 m, 0.75 m, and 1.00 m, representing shallow to moderately deep conditions. These depths were selected to investigate the transition between local and general shear failure in sandy soils [16]. The relative densities were controlled at 27%, 50%, and 80%, corresponding to loose, medium, and dense sand states, respectively. These levels were selected to examine the influence of inter-particle friction and interlocking on shear mobilization [24, 25]. Wing opening angles were set at 0°, 30°, 45°, 60°, and 75° (see Figure 4) to evaluate the influence of expansion geometry on passive resistance and pullout capacity [26, 27]. Wing deployment was achieved by applying controlled torque to the central rod of the anchor, while pullout loading was applied using a hydraulic jack with a capacity of 100 kN, monitored through a 20 kN load cell mounted on a rigid steel frame. Displacements were measured by a Linear Variable Differential Transformer (LVDT), and all data were continuously recorded with a digital data logger.

2.1. Soil Preparation

The sand used in this research was obtained from the Progo River, located in the Special Region of Yogyakarta, Indonesia. The material was free from organic matter and classified according to the Unified Soil Classification System (USCS) as a mixture of well-graded sand (SW) and silty sand (SM). Before testing, the material was sieved through a No.10 (2 mm) sieve to obtain a uniform gradation suitable for controlled compaction. Although the sand contained a small fraction of fines, its overall behavior remained predominantly frictional, typical of granular soils used in anchoring studies. The slight presence of fines may affect packing density and dilation, but the pullout mechanism is still primarily controlled by relative density, embedment depth, and anchor geometry. Therefore, the results are consistent with previous studies using clean sand, while remaining representative of real field conditions.

The index and physical properties of the sand were determined according to ASTM standards and are presented in Table 1. Tests included unit weight, specific gravity, grain size analysis, and USCS classification following ASTM D422, ASTM D2487, and Test Methods for Specific Gravity of Soil Solids by Water Pycnometer [28]. The results show the material consists of 98.37% sand and 1.63% gravel, confirming its classification as well-graded sand with minor silt content. To achieve the target relative densities ($D_r = 27\%$, 50%, and 80%), the sand was compacted inside the cylindrical tank to corresponding dry unit weights (γ_d). The relationship between γ_d and D_r was established experimentally, as shown in Figure 2, and served as a reference for density control during soil placement. The minimum (γ_{\min}) and maximum (γ_{\max}) dry unit weights were determined using ASTM D4253 (2016) via the vibratory table method. The target γ_d for each test was obtained from the γ_d - D_r curve using graphical interpolation. For example, at $D_r = 50\%$, the corresponding $\gamma_d = 1.36 \text{ g/cm}^3$ (1360 kg/m³). Considering a sand fill height of 1.0 m in the 1.2 m diameter tank, the total fill volume was calculated as $V = \pi(0.6)^2 \times 1.0 = 1.13 \text{ m}^3$, requiring approximately 1.54 tons of dry sand. The same procedure was applied for the other density levels (27% and 80%) and embedment variations.

Table 1. Physical properties of the sand

Test type	Standard	Parameter	Unit	Result
Unit weight		γ_b	kN/m ³	19.9
Specific gravity	ASTM D854-14 [29]	G_s	—	2.64
Grain size analysis	ASTM D422-63 [28]	Gravel	%	1.63
		Sand	%	98.37
Classification, USCS	ASTM D2487-17 [30]		—	Well graded sand and silty sand

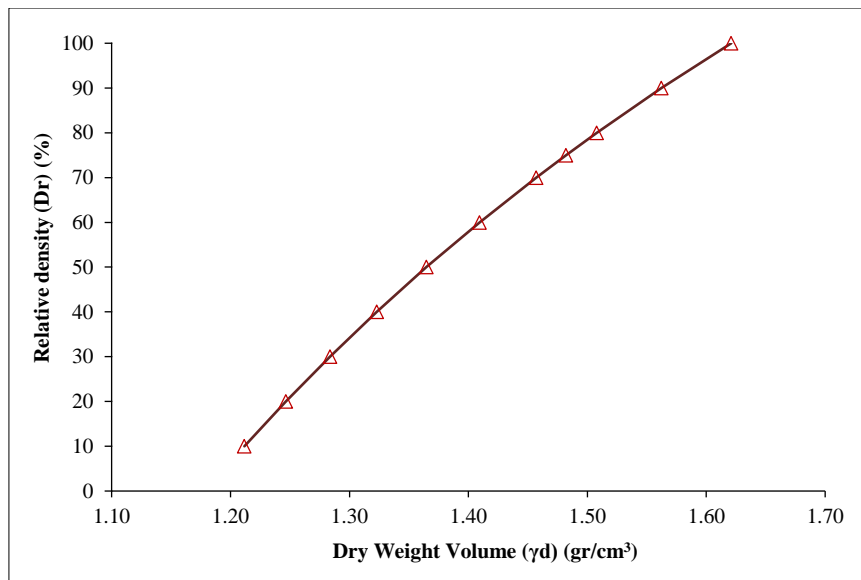
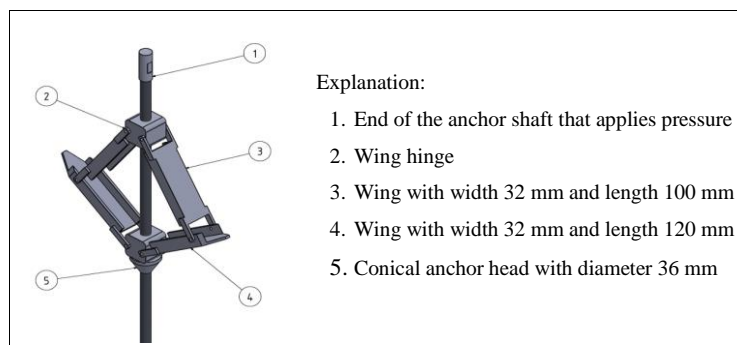


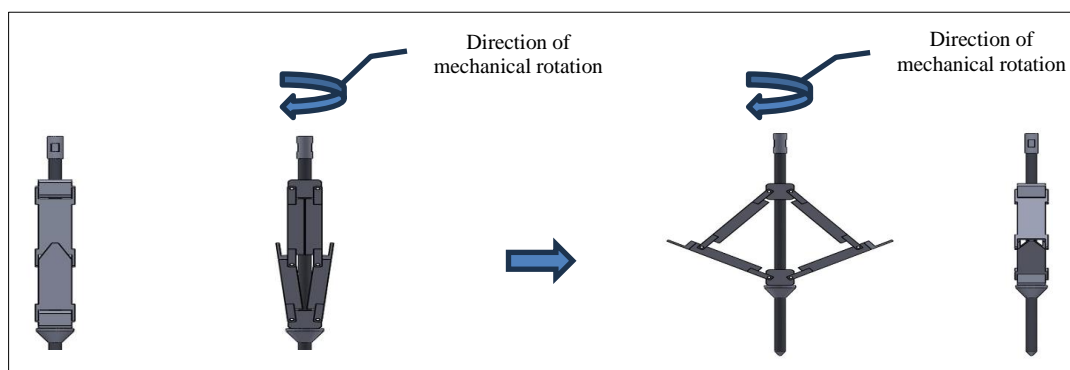
Figure 2. Relationship between unit weight and relative density

2.2. Jack-like Ground Anchor Prototype

The jack-like ground anchor prototype was designed to replicate the operational principle of an automotive scissor jack, enabling mechanical expansion of the wings after installation. The system consists of three main components: the anchor head, the deployable wing body, and the anchor shaft (Figure 3-a). The anchor head has a conical shape with a 36 mm diameter, fabricated from solid steel to facilitate penetration and reduce installation resistance. The wing body, functioning as the expandable part, comprises two hinged plates each 32 mm wide and 4 mm thick. These wings can open symmetrically through a central hinge mechanism, providing adjustable angles between 0° and 75° depending on the torque applied.



(a)



(b)

Figure 3. (a) Components of the jack anchor; (b) Direction of mechanical rotation applied to the jack anchor shaft

The anchor shaft, made of 12 mm diameter steel rod, transfers torque to the wings and connects the assembly to the loading system at the surface. The shaft is enclosed within a 22 mm diameter steel tube, which acts as both a protective casing against corrosion and a guide sleeve for smooth rotation. The total anchor length is approximately 400 mm,

suitable for small-scale testing while maintaining geometric similarity to field anchors. Wing deployment is achieved by applying mechanical rotation to the shaft, which converts rotational motion into lateral expansion (Figure 3-b). This mechanism increases the effective bearing area and passive resistance around the anchor without requiring additional soil disturbance. The adjustability of the wing opening angle allows systematic evaluation of how anchor geometry influences the development of shear and uplift resistance in sand. Photographs of the fabricated prototype and configurations with different opening angles (0°, 30°, 45°, 60°, and 75°) are shown in Figure 4, which represent the range of test parameters used in this study.

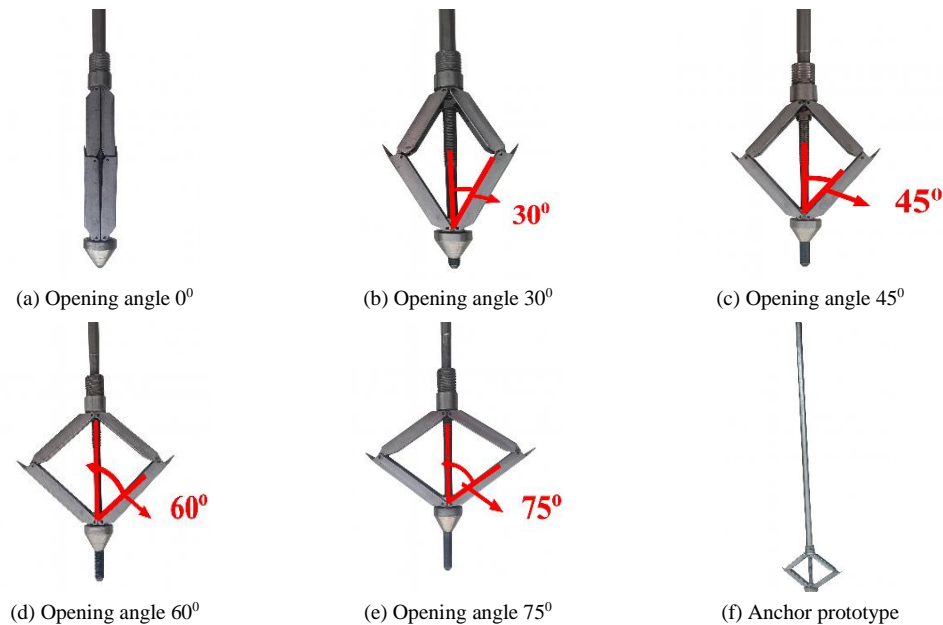


Figure 3. Anchor configurations used in the study with opening angle variations

2.3. Test Setup

The overall workflow of this research is summarized in Figure 5, which illustrates the sequential stages from concept development to experimental evaluation. The process began with an extensive literature review to identify research gaps and performance limitations of existing anchor systems. The concept of the jack-like ground anchor was then developed and refined, followed by material preparation, soil characterization, and prototype fabrication. Laboratory pullout testing was subsequently performed to evaluate the mechanical behavior of the prototype under controlled conditions. The experimental data were processed and interpreted to determine the pullout capacity and the corresponding load-displacement response, forming the basis for the results and conclusions presented in later sections.

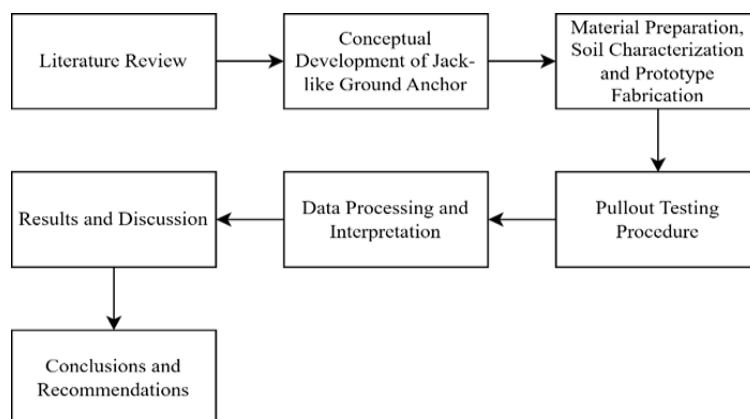


Figure 4. Flowchart of the research methodology

The pullout testing setup is shown schematically in Figure 6. The system comprised a rigid steel loading frame (1) supporting a hydraulic jack (2) and bearing plate (3) positioned vertically above the anchor. A 20 kN load cell (4) was installed inline between the jack and the anchor rod to measure the applied tensile load. The anchor was embedded in a cylindrical steel box (5) filled with sand media (9), and connected to a digital data logger (7) for continuous recording of load and displacement through an LVDT sensor. The entire test assembly was placed on a rigid wooden base (8) to ensure stability and minimize vibration effects.

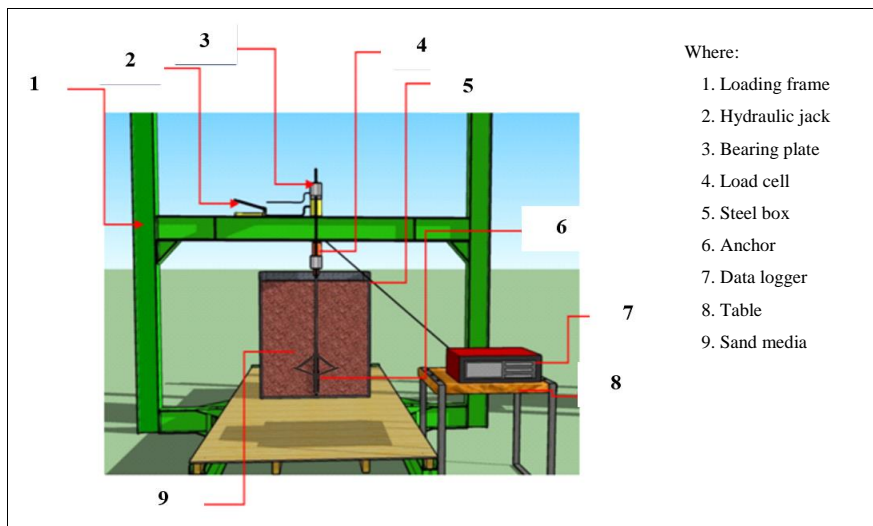


Figure 5. Test setup

Prior to testing, sand was placed and compacted in layers to achieve the specified relative densities of 27%, 50%, and 80%, representing loose, medium, and dense states, respectively. The anchor was installed at embedment depths of 0.50 m, 0.75 m, and 1.00 m, and the wings were set to opening angles of 0°, 30°, 45°, 60°, and 75°. The fully closed condition (0°) served as the reference configuration, while the maximum opening angle of 75° represented the largest stable expansion achievable by the prototype without inducing excessive soil disturbance. These configurations were selected to capture the transition between shallow and moderately deep anchor behavior and to investigate the coupled effects of embedment, relative density, and anchor geometry on pullout resistance.

The pullout load was applied vertically in an upward direction using the hydraulic jack under displacement-controlled loading at a rate of approximately 1 mm/min to maintain quasi-static conditions. Each test configuration was repeated three times to ensure repeatability. The reported pullout capacity represents the average value of the three tests, while the standard deviation was used to evaluate the consistency of the data. Across all configurations, the variability was found to be less than 5%, confirming the reliability of the experimental procedure.

Photographs of the actual laboratory testing process are shown in Figure 7, illustrating (a) the pullout testing setup, (b) the backfilling process over the installed anchor, (c) the anchor ready for testing, and (d) the condition of the anchor immediately after testing. These images provide a visual representation of the procedures described and validate the systematic approach used during the experimental phase.



Figure 6. (a) Pullout testing of the jack anchor (b) Backfilling over the jack-like ground anchor; (c) Jack anchor ready for testing; (d) Jack anchor after testing

The main experimental output was the load-displacement curve, from which the ultimate pullout capacity (Q_{ult}) was determined using the Mazurkiewicz method [31], as shown in Figure 8. In this graphical interpretation, the ultimate load corresponds to the intersection point between the tangent drawn from the initial linear portion of the curve and a line inclined at 45° to the horizontal axis from the point of maximum load deflection. This method provides a consistent and objective means of defining the ultimate capacity across different test configurations and soil densities.

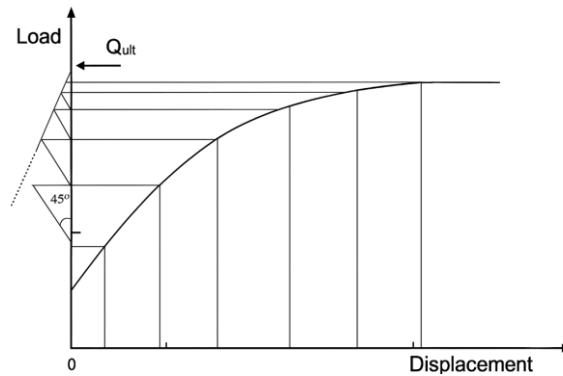


Figure 7. Graph illustrating the Mazurkiewicz method [31]

3. Results and Discussions

3.1. Relationship between Pullout Capacity and Embedment Ratio

The relationship between pullout capacity and the embedment ratio ($R = H/B$) for various relative densities (Dr) and embedment depths (H) is illustrated in Figure 9. The results clearly show that increasing the wing opening angle and relative density significantly enhances pullout capacity. This improvement occurs because a larger opening angle increases the effective soil anchor interface, thereby mobilizing greater passive resistance. The observed trend agrees with findings by Tilak & Samadhiya [27], who reported that expansion type anchors in dense sand exhibited higher uplift resistance due to improved shear mobilization along the soil anchor interface. The maximum pullout capacity was achieved for $Dr = 80\%$ and $H = 100$ cm, reaching approximately 13 kN at low R values. This indicates that higher relative density enhances interparticle friction and dilation, leading to stronger soil anchor bonding. At this density, the soil particles form a more stable contact network that transfers shear forces more effectively, resulting in an extended failure zone and greater load transfer efficiency. Similar observations have been reported in previous studies on helical and plate anchors, where dense sand conditions produced greater tensile resistance due to increased interlocking and reduced particle slippage [24, 26].

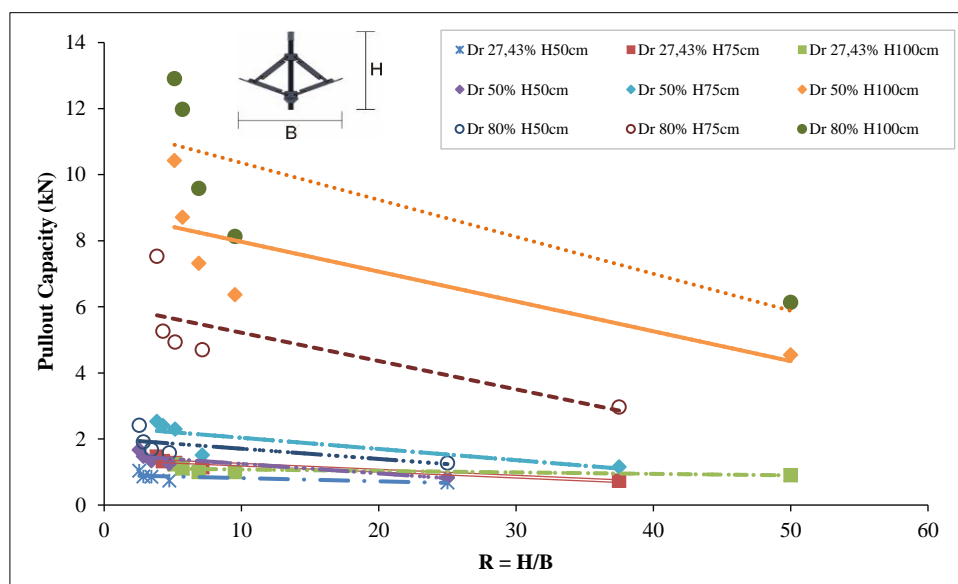


Figure 8. Relationship between embedment ratio $R = H/B$ and pullout capacity

In contrast, anchors installed in loose sand ($Dr = 27\%$) exhibited significantly lower capacities, typically below 2 kN. This reduction is attributed to the limited frictional resistance and lack of inter-particle contact in loose soils, which hinder the formation of a well-defined failure surface. Consequently, the anchor mobilizes less passive resistance, and

the pullout failure tends to occur prematurely. This behavior corresponds to the general pattern observed by Zhu et al. [32], who found that decreasing soil density reduces the stiffness of the load–displacement response and the magnitude of ultimate uplift capacity. Embedment depth also plays a crucial role, particularly at low values of R . The configuration with $D_r = 80\%$ and $H = 100$ cm demonstrated the highest pullout capacity (12–13 kN), suggesting that adequate embedment depth ensures full mobilization of the frictional and passive resistance zones. However, as R increases, the rate of capacity improvement diminishes, indicating that beyond a certain embedment ratio, the additional depth contributes minimally to uplift resistance. This trend aligns with theoretical models proposed by Ezzein & Bathurst [33] and Mohamed [34], which suggest that once the failure mechanism transitions from local to general shear, further embedment produces negligible gains in capacity.

Overall, the relationship between pullout capacity and embedment ratio confirms that anchor performance in granular soils is governed by the combined influence of relative density, embedment depth, and mobilized shear zone geometry. Dense soils and moderate embedment ratios yield the most efficient uplift response, while excessively deep installations provide limited benefit relative to the increased installation effort.

3.2. Role of wing Opening Angle in Shear Mobilization

Figure 10 illustrates the variation of pullout capacity with relative density for different wing opening angles. The results demonstrate that the wing opening angle plays a dominant role in controlling the mobilization of tensile resistance within the soil anchor interface. As the wing angle increases from 0° to 75° , the effective contact area between the anchor and the surrounding sand expands, leading to greater passive resistance and shear mobilization. This confirms that the geometry of the jack-like anchor directly governs the efficiency of load transfer in granular soils. For loose sand ($D_r = 27\%$), the pullout capacity remains low for all wing angles. The limited improvement even at larger openings indicates that the surrounding soil provides insufficient confinement to sustain passive resistance. This trend aligns with the findings of Guntuka & Kumar Nandyala [35], who observed that in loose sands, the absence of interlocking among grains prevents the development of a stable shear surface, thereby restricting the contribution of anchor geometry.

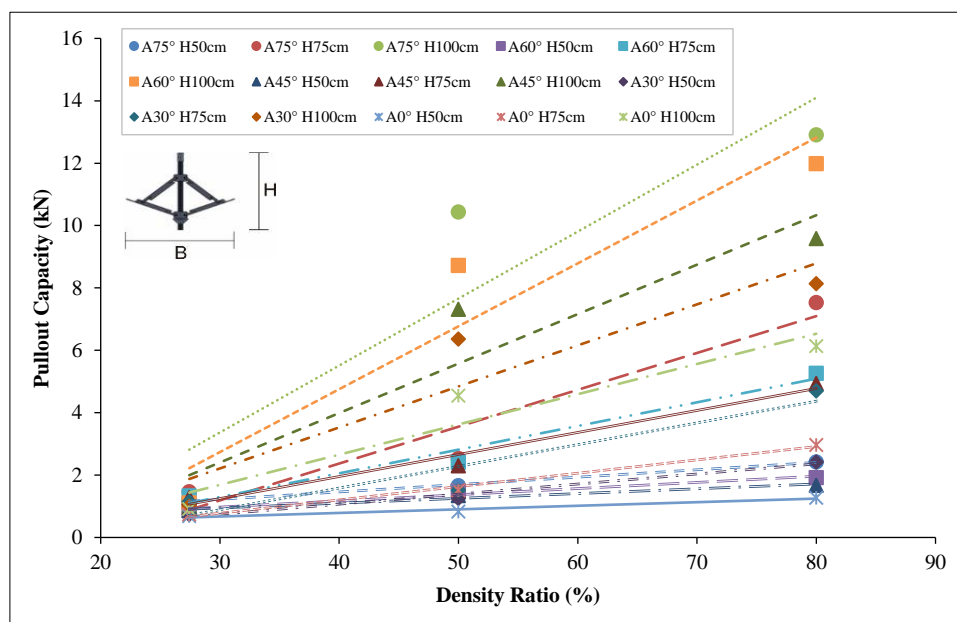


Figure 9. Pullout capacity for several wing openings at different relative densities

At medium relative density ($D_r = 50\%$), the influence of wing opening becomes more evident. The pullout capacity increases substantially with larger wing angles, particularly between 60° and 75° , due to enhanced inter particle contact and mobilized shear resistance. In this condition, the soil is sufficiently compact to allow dilation and the formation of a passive wedge during pullout, which amplifies the contribution of the expanded wings [36, 37]. This behavior demonstrates the synergistic interaction between soil density and wing geometry in developing tensile capacity. In dense sand ($D_r = 80\%$), the effect of wing opening is most pronounced. The pullout capacity of the anchor with a 75° opening reaches approximately 15–16 kN, whereas the 0° configuration achieves only about 5–6 kN. This corresponds to an improvement exceeding 200%, primarily attributed to the larger mobilized failure surface and the increased interface friction resulting from greater soil confinement. These findings are consistent with the results of Tilak & Samadhiya [27], who reported similar enhancement trends for expandable anchors tested in dense granular media. The mechanical expansion of the jack-like anchor effectively transforms local shear around the shaft into a broader passive failure zone, producing a highly efficient load transfer mechanism [38, 39].

In summary, the results confirm that the wing opening angle is the most critical geometric parameter influencing the mobilization of shear resistance in sand. Wider openings significantly increase the mobilized soil volume and frictional contact area, whereas narrow or closed configurations provide limited engagement. The jack-like anchor’s expandability enables adaptive optimization of its performance across varying soil densities, validating its potential as an efficient and versatile ground anchoring system.

3.3. Impact of Relative Density and Geometry on Pullout Resistance

Figure 11 presents the relationship between embedment depth and pullout capacity for various combinations of wing opening angles and relative densities (Dr). The results show that relative density exerts the most dominant influence on the pullout behavior of the jack-like ground anchor, governing the degree of interparticle friction and the extent of the mobilized shear zone around the anchor. At low density (Dr = 27%), the pullout capacity remains minimal across all embedment depths and wing configurations, with maximum values slightly exceeding 2.0 kN. This limited performance results from weak interlocking between soil particles, which prevents the formation of a continuous shear surface and confines the load transfer zone to a small region near the anchor. Consequently, deeper embedment does not significantly enhance resistance since the soil’s internal friction is insufficient to support tensile loads. Similar observations have been reported by Kumar et al. [40], Liang et al. [41] who found that in loose granular media, the shear strength mobilized during uplift is rapidly lost due to particle rearrangement and localized deformation.

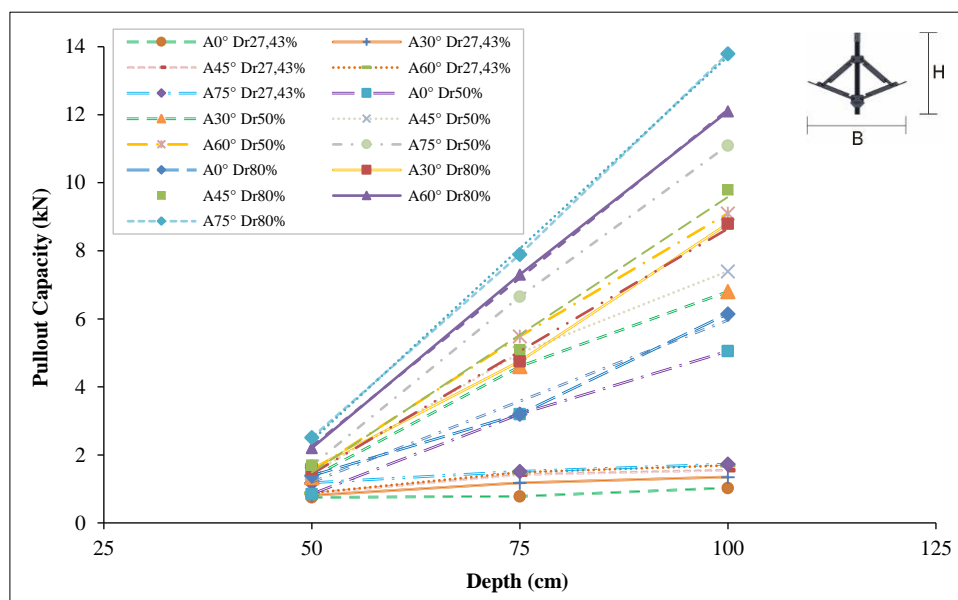


Figure 10. Relationship between embedment depth and pullout capacity for different wing openings and relative densities

As the relative density increases to Dr = 50%, the anchor behavior transitions from localized to general shear failure. The pullout capacity rises sharply, reaching approximately 10-12 kN for a 75° wing opening at H = 100 cm. This improvement is attributed to stronger interparticle contacts and dilation effects, which allow a larger volume of soil to participate in load transfer. The mobilized passive resistance zone expands laterally, and frictional resistance becomes the dominant mechanism. These results are consistent with experimental findings by Peng et al. [36], and Wu et al. [37] who demonstrated that denser sands exhibit enhanced dilatancy and greater shear resistance under uplift loading. In dense sand (Dr = 80%), the effect of geometry is most pronounced. The pullout capacity approaches 14 kN at H = 100 cm with a 75° wing opening, representing more than a 200% increase compared to the closed wing configuration under the same conditions. This behavior is due to strong interlocking and high internal friction, which enable the anchor to mobilize a broad, stable failure surface extending upward toward the ground surface. The dense packing of particles also minimizes volumetric strain, maintaining confinement during uplift and allowing the anchor to achieve its full mechanical efficiency. This finding aligns with those of Chen et al. [42], and Li et al. [43] who observed that anchors in dense granular soils benefit from both enhanced interface friction and enlarged passive zones.

Overall, the interaction between relative density and geometry (wing opening and embedment depth) governs the pullout response of the jack-like anchor. Loose sands deform readily with minimal resistance, while denser sands with expanded wing configurations mobilize greater frictional and bearing resistance. A combination of high relative density, moderate embedment depth, and large wing opening consistently yields the highest pullout capacity, confirming the critical role of soil compaction in optimizing anchor performance [44, 45].

4. Conclusion

The jack-like ground anchor represents an innovative anchoring system that operates on the mechanical principle of an automotive scissor jack. Its expandable wings, which are deployed after installation, significantly increase the soil anchor contact area and enhance the mobilization of shear resistance and passive pressure. The experimental results in sand with varying relative densities, wing opening angles, and embedment depths demonstrate that the performance of this anchor is strongly governed by the combined interaction between soil density and anchor geometry.

The findings reveal that higher relative density and greater embedment depth lead to a more extensive mobilized shear zone and higher pullout capacity. In dense sand ($D_r = 80\%$), interparticle friction and dilation effects improve the efficiency of load transfer, while the expanded wing configuration (60° - 75°) provides a substantial increase in the effective bearing area. Conversely, in loose sand, weak particle interlocking limits the mobilization of passive resistance, resulting in significantly lower capacity regardless of geometry. The results also indicate that increasing embedment depth beyond a certain level yields diminishing returns, suggesting that anchor design should prioritize optimal geometry and compaction rather than excessive depth. Overall, the combination of high relative density, moderate embedment ratio, and large wing opening consistently yields superior pullout performance. These findings provide a strong foundation for developing adaptive anchoring systems capable of optimizing soil structure interaction under varying field conditions.

5. Declarations

5.1. Author Contributions

Conceptualization, D.E.W. and Y.M.P.; methodology, D.E.W. and Y.M.P.; validation, Y.M.P., B.S., and G.C.; formal analysis, D.E.W.; investigation, D.E.W.; writing—original draft preparation, D.E.W.; writing—review and editing, D.E.W.; visualization, D.E.W.; supervision, G.C. and B.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Acknowledgments

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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