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Research Article

Determination of Diameter of Belled Shafts with respect to Uplift Forces Resulted from Expansive Soil Layer in Active Zone

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Abstract

Expansive soils are found in many parts of the world that are especially arid and semi-arid regions. They have caused several damages of lightweight structures for decades. For this reason, a more suitable foundation type should be selected and designed for the lightweight structures built on these soils. For example, the application of belled shaft foundation at expansive soil layer is preferable method in practice. However, one of the worst cases at the design of this foundation is accepted that the swelling of expansive soil placed in active zone. Therefore, this condition should be taken into account at the design process of this foundation. In this study, the diameter of belled shaft was separately determined with respect to some factors such as the diameter of shaft, the depth of active zone, the friction angle between shaft and soil, and the ratio between the undrained cohesion of soil at stable zone and the swelling pressure of expansive soil placed in active zone. In the calculation process, four different shaft diameters that are 0.3 m, 0. 45 m, 0.60 m, and 0.75 m were utilized. Also the depth of active zone that started from 1.5 m to 15 m was specified. To sum up, the optimum shaft diameter was found as 0.45 m.

Keywords: Belled shaft, Expansive soil, Active zone, Swelling pressure, Cohesion

Aktif Bölgedeki Şişen Zemin Tabakasından Kaynaklanan Kaldırma Kuvvetine Göre Genişletilmiş Şaftın Çapının Belirlenmesi

Öz

Şişen zeminler, dünyanın birçok bölümünde özellikle yarı kurak ve kurak bölgelerinde bulunmaktadır. Bu zeminler, yılarca hafif yapılarda hasarlara neden olmaktadır. Bu yüzden, bu zeminlerin üzerine inşa edilecek yapılar için en uygun temel tipi seçilmeli ve tasarlanmalıdır. Örneğin, genişletilmiş şaft temel uygulaması pratikte tercih edilen bir metottur. Bununla birlikte, aktif bölgede yer alan şişen zeminin kabarması bu temel tasarımındaki en kötü senaryolardan bir tanesi olarak kabul edilmektedir. Bu yüzden bu temelin tasarım sürecinde bu durum göz önüne alınmalıdır. Bu çalışmada, genişletilmiş şaftın çapı; şaftın çapı, aktif bölge derinliği, şaft ve zemin arasındaki sürtünme açısı ve sağlam bölgedeki zeminin drenajsız kohezyonu ile aktif bölgede yer alan zeminin şişme basıncı arasındaki oran gibi faktörler dikkate alınarak ayrı ayrı hesaplanmıştır. Hesaplama sürecinde, dört farklı şaft çapı (0.3 m, 0. 45 m, 0.60 m ve 0.75 m) kullanıldı ayrıca 1.5 metre ile 15 metre arasında aktif bölge derinliği belirlendi. Özet olarak, optimum şaft çapı 0.45 m olarak bulunmuştur.

Anahtar Kelimeler: Genişletilimiş şaft, Şişen zemin, Aktif bölge, Şişme basıncı, Kohezyon

1. Introduction

Expansive soils are generally known as problematic soils by civil engineers as the volumes of these soils depend on the water content of these soils. Thus, several damages of lightweight structures are originated in the change of volumes of these soils. To sum up, these damages generally induce considerable economic loss rather than life loss. These soils are found in many parts of the world that have especially semi-arid or arid regions. Turkey is one of the richest countries in terms of the deposits of expansive soil. These deposits are particularly in some parts of this country such as Central Anatolia region, West Anatolia region, Southeast Anatolia region and East Anatolia region (Chen 1988, Çokça 1991, Hong 2008, Mishra et al. 2008, Nelson et al. 2015, Parhi et al 2017).

Expansive soils have been intensively studied for last decades. While some of these studies related to the stabilization of these soils, some of them are investigated in the suitable foundation for the structures built on these soils. In addition to this, chemical stabilization, compaction, removal and replacement are commonly preferable methods to improve these soils. As these methods are generally suitable for upper layer, these methods is not feasible for a layer placed in deeper. For this reason, a drilled shaft foundation is applied for expansive soil layer. At the application of this foundation type, the length of drilled shaft should be greater than active zone of expansive soil that is defined that a region has heave potential. Since a part of drilled shaft that is found at the active zone may be subjected to uplift forces formed the result of swelling of expansive soil. To solve this problem, the active zone should be carefully determined prior to design of this foundation type (Nelson and Milner 1992, Nelson et al. 2001, Brown et al. 2010, Nelson et al. 2015, Das and Sivakugan 2018).

Two different types of drilled shaft foundation may be constructed at the field with respect to the properties of soil layer. These types are named as straight and belled shaft in practice (Figure 1).

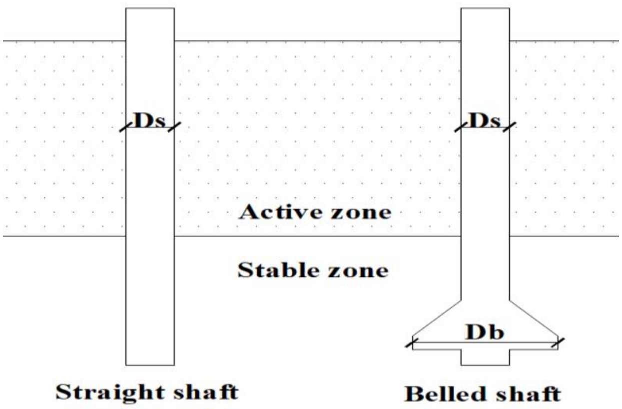

Figure 1. Straight shaft and belled shaft

The straight shaft foundation is usually utilized when it is either socketed or lapped in rock layer. Belled shaft that is known as underreamed shaft is more advisable foundation type for the soil layer that has very deep soft soil such as expansive soil, loose sand etc. (Brown et al. 2010, Das and Sivakugan 2018).

The dimensions of belled shaft depend on some soil parameters that are called as active zone, swelling pressure, and undrained cohesion. Active zone may alter some factors that are climatic condition, drainage, gradation etc.. The values of both swelling pressure and undrained cohesion of expansive soil affect many soil properties that are clay mineralogy, dry density, plasticity index, water content (Ajmera et al. 2012, Zumrawi 2012, Su et al. 2018).

Uplift forces resulted from expansive soil in active zone depend heavily on the diameter of shaft and the roughness between shaft and soil. The diameter of shaft can be both selected and applied with a wide range in the field. However, the diameter of shaft foundation built in expansive soil layer should be determined at lower value. Since, the uplift force increases with the diameter of shaft due to the rise of friction area. The roughness between shaft and soil (Nelson and Milner 1992, Kulhawy 1991, Das and Sivakugan 2018).

The diameter of belled shaft was determined with respect to some parameter that are diameter of shaft, the ratio between unconfined cohesion and swelling pressure, and the depth of active zone. To sum up, main aim of this study is an assumption of the ratio between belled shaft diameter and shaft diameter by using these parameters mentioned above.

2. Materials and Methods

Methodology of this study is given at this part. Then, information of both soil profile and belled shaft were examined in detail.

2.1 Capacity of Belled Shaft Against Uplift Force

The capacity of belled shaft against uplift force is calculated with respect to Figure 2.

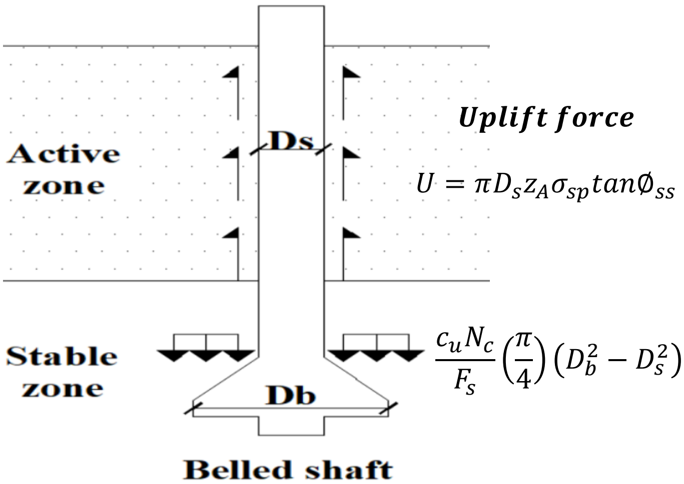

Figure 2. Uplift force and the capacity of belled shaft

Uplift force results from the swelling of expansive soil existed in active zone. This force are determined by using Equation 1.

$$U = \pi D_s z_A \sigma_{sp} tan\emptyset_{ss} \qquad Eq. 1$$

where z_A is the depth of active zone in expansive soil layer. Swelling pressure of expansive soil found in active zone is shown as σ_{sp} in Eq. 1. The friction angle between shaft and soil are illustrated as $\emptyset_{ss}$ in this equation.

The capacity of belled shaft was calculated at heaving condition by using Equation 2 that is given below (Das and Sivakugan 2018).

$$Q_{net} = U - D = \frac{c_u N_c}{F_s}\left(\frac{\pi}{4}\right)\left(D_b^2 - D_s^2\right) \qquad Eq. 2$$

where U and D are represented uplift force and dead load, respectively. Dead load is taken zero at worst condition in this equation. c_u is undrained cohesion at stable zone of expansive layer. N_c is bearing capacity factor and the value of this parameter is taken as 6.14 in this study. F_s is factor of safety and is generally assumed as 1.25 (Das and Sivakugan 2018). The diameter of both belled shaft and shaft are shown as D_b and D_s in Equation 2, respectively.

The parameters given in both Equation 1 and Equation 2 are examined in detail. ,

2.2 Profile and Parameters of Soil Layer

Soil profile was assumed as deeper expansive soil layer. In other words, either bedrock or rigid stratum is existed at very deep.

Two properties of soil that are undrained cohesion and swelling pressure are seminal parameters for the design of belled shaft foundation. Besides these parameters, the depth of active zone is another keystone properties of soil layer. However, these parameters may change according to some soil properties such as dry density, clay mineralogy, water content etc.. Thus, these parameters generally alter from region to region. An extensive both site investigation and laboratory work should be done prior to the design of belled shaft.

In practice, undrained cohesion(c_u), swelling pressure(σ_{sp}), and the depth of active zone of expansive soil layer (z_A) are measured after both site investigation and laboratory work. Each design of belled shaft foundation are evaluated as independent and original when expansive soil deposits are considered.

A parameter, which is presented as a ratio between undrained cohesion and swelling pressure of soil was assumed to facilitate this problem. The ratio between undrained cohesion of expansive soil at stable zone and swelling pressure of expansive soil existed in active zone were estimated as 0.25, 0.5, 0.75, and 1, respectively.

The depths of active zone have been reported as a wide range that starts from 1.5 m to 15 m for expansive soil deposits in the world. Therefore, the depth of active zone was verified from 1.5 m to 15 m (O'Neill and Poormoayed 1980, Das and Sivakugan 2018).

2.3 Parameters of Belled Shaft

Three parameters related to belled shaft foundation, which are the diameter of shaft, the friction angle between shaft and soil, and the length of belled shaft were investigated in the scope of this study.

Four different values of shaft diameter were selected as 0.3m, 0.45 m, 0.60 m, and 0.75 m, respectively. The diameter of belled shaft was separately calculated with respect to the diameter of shaft.

The friction angle between shaft and soil is utilized the calculation of either friction force at loading condition or uplift force at swelling condition. This angle are generally alters from 10° to 20° (Das and Sivakugan 2018).

The length of belled shaft was easily determined with respect to both the depth of active zone and stable zone at expansive soil layer.

3. Results

The design of belled shaft that built in expansive soil layer is specific as this process depends on some factors such as field conditions, shaft properties, soil properties etc. Thus, the diameter of belled shaft alters due to the change any of these parameters. For this reason, the diameters of belled shaft were calculated by using two parameters that are the ratio between undrained cohesion of expansive soil at stable zone and swelling pressure of expansive soil in active zone, and the depth of active zone by using the diameter of shaft.

Four different shaft diameter that 0.3 m, 0.45 m, 0.6 m, and 0.75 m and six different friction angles between shaft and soil that are $10^{\circ}, 12^{\circ}, 14^{\circ}, 16^{\circ}, 18^{\circ}, and\ 20^{\circ}$ were selected in this study. Besides these, two different soil parameters were used in the calculation step of this study. First parameter is the ratio between undrained cohesion of expansive soil at stable zone and swelling pressure of expansive soil existed in active zone and the values of these parameters are accepted as 0.25, 0.5, 0.75, and 1 in this study. The second one is depth of active zone of expansive soil layer and the value of this parameter alter from 1.5 m to 15 m.

Fifteen graphs were plotted after the calculation process. These graphs are given in Figure 3-6 with respect to the diameter of shaft.

Belled diameter should be greater than shaft diameter and the maximum belled diameter cannot be greater than three times shaft diameter due to the structural design. Thus, the ratio between belled diameter and shaft diameter is determined from 1 to 3. In addition to this, this ratio increases with the depth of active zone in expansive soil layer.

The possibility of the construction of belled shaft in expansive soil layer depends on the ratio between undrained cohesion of expansive soil at stable zone and swelling pressure of expansive soil existed in active zone. When swelling pressure of expansive soil in active zone is much greater than undrained cohesion of expansive soil in stable zone, the achievement of belled shaft is not enough against uplift force.

The increase of friction angle between shaft and soil result in the raise of uplift force. The decrease of void ratio of expansive soil result in the decrease of contact area between shaft and soil. In addition to this, the roughness of shaft affects friction angle between shaft and soil. For this reason, the roughness between shaft and soil should be minimized. Thus, the greater friction angle between shaft and soil needs the greater belled diameter.

The diameter of shaft that is either 0.3 m or 0.45 m is suitable for the deeper expansive soil layer (approximately 15 m). However, the maximum depth of active zone should be lower than 9 m for the shaft diameter that is 0.6 m. In addition to this, this value is lower (approximately 7 m) for 0.75 m shaft diameter. In conclusion, the depth of active zone is keystone parameter for the selection of shaft diameter.

The optimum shaft diameter was found as 0.45 m in the calculation process for all properties of both soil and shaft.

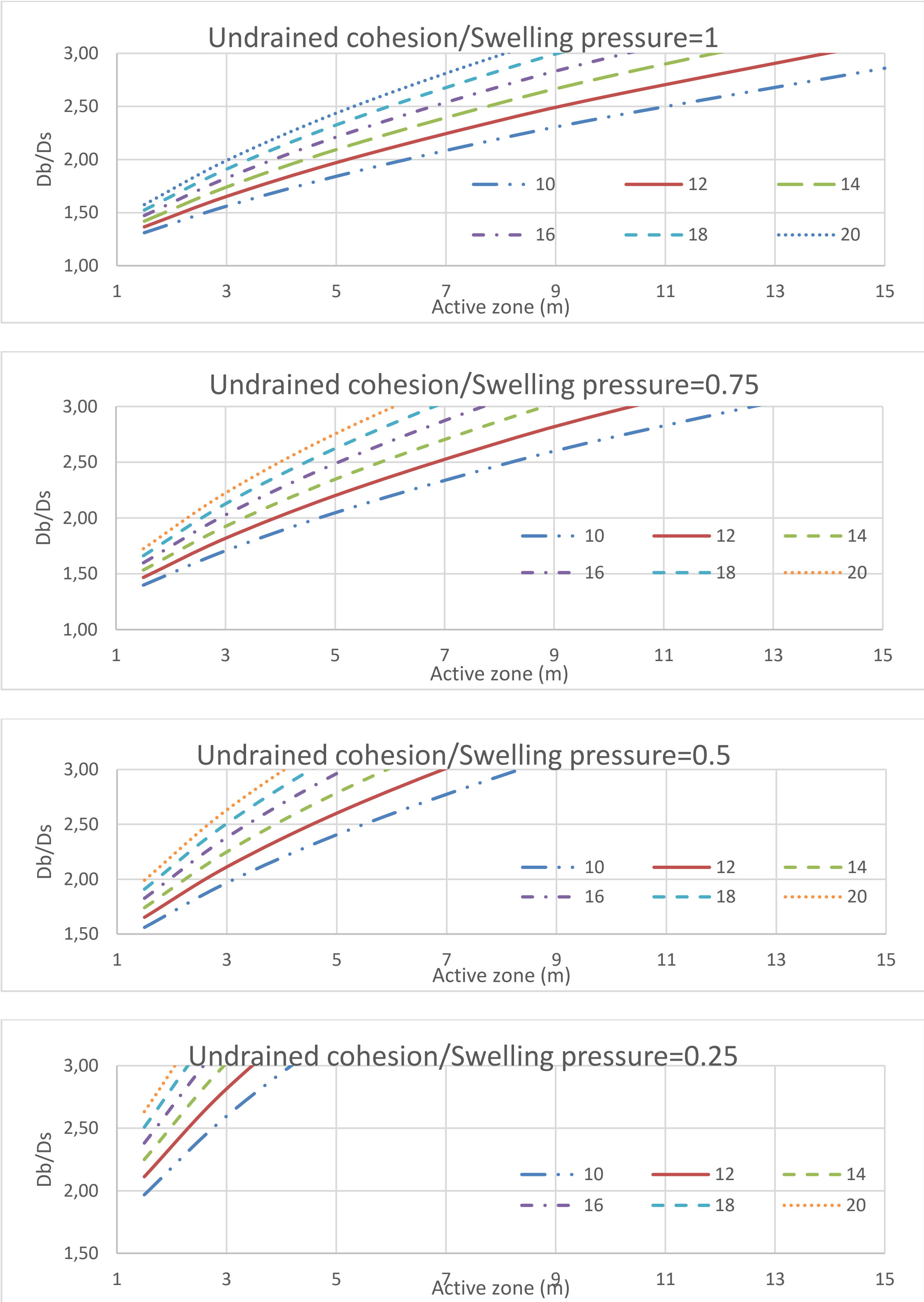

Figure 3. The diameter of belled shaft with respect to the depth of active zone, the friction angle between shaft and soil, and 0.3 m shaft diameter

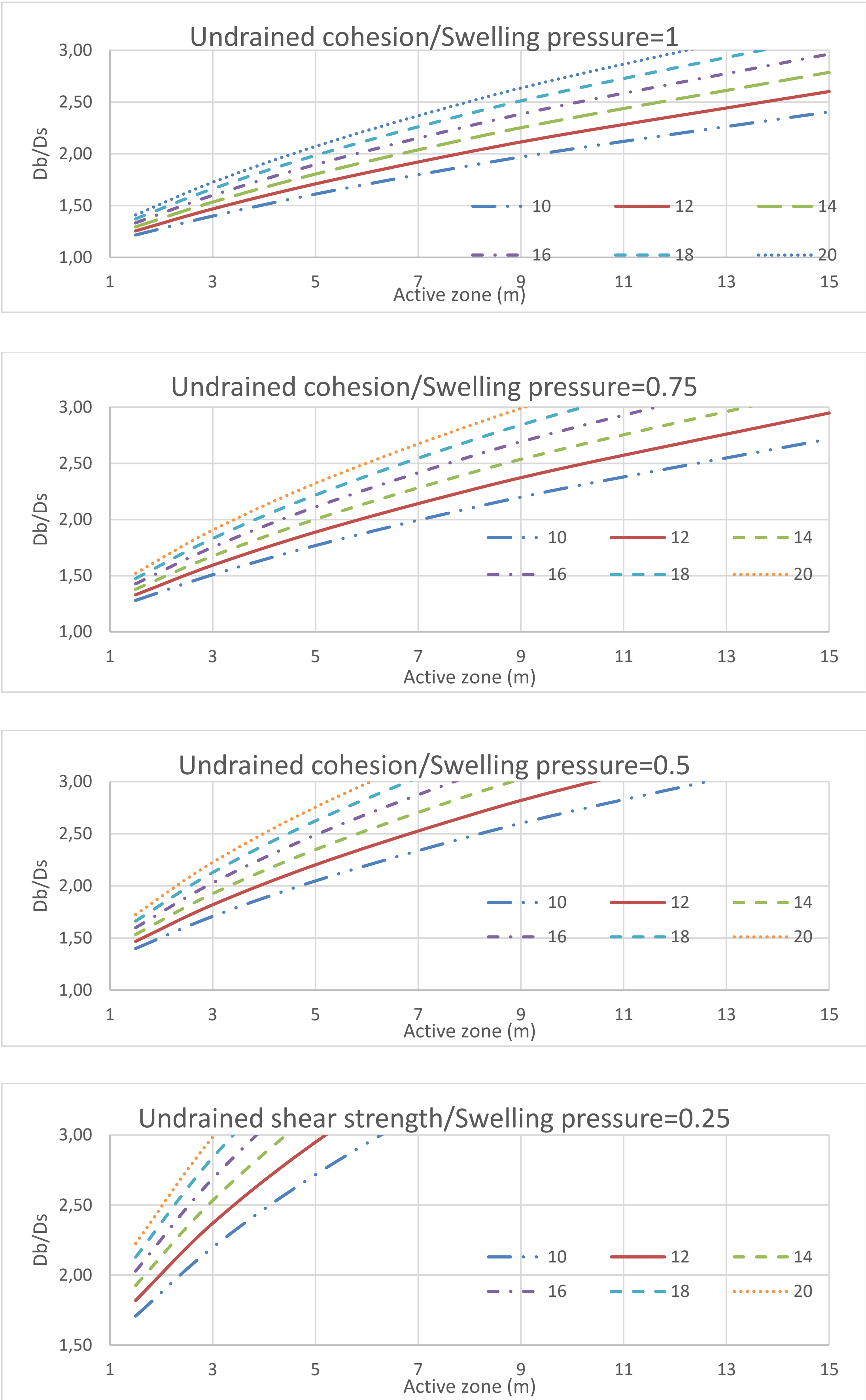

Figure 4. The diameter of belled shaft with respect to the depth of active zone, the friction angle between shaft and soil, and 0.45 m shaft diameter

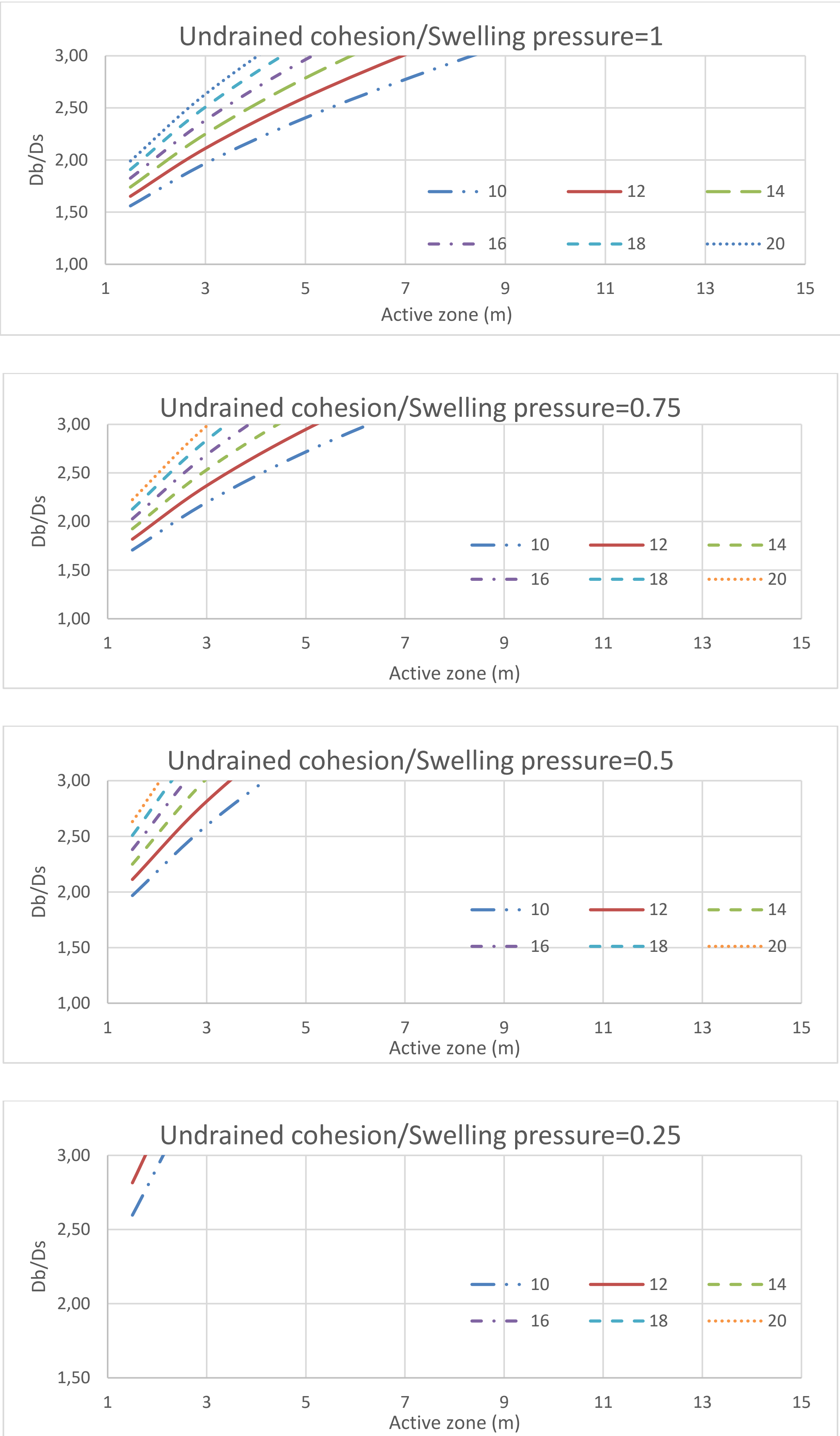

Figure 5. The diameter of belled shaft with respect to the depth of active zone, the friction angle between shaft and soil, and 0.6 m shaft diameter

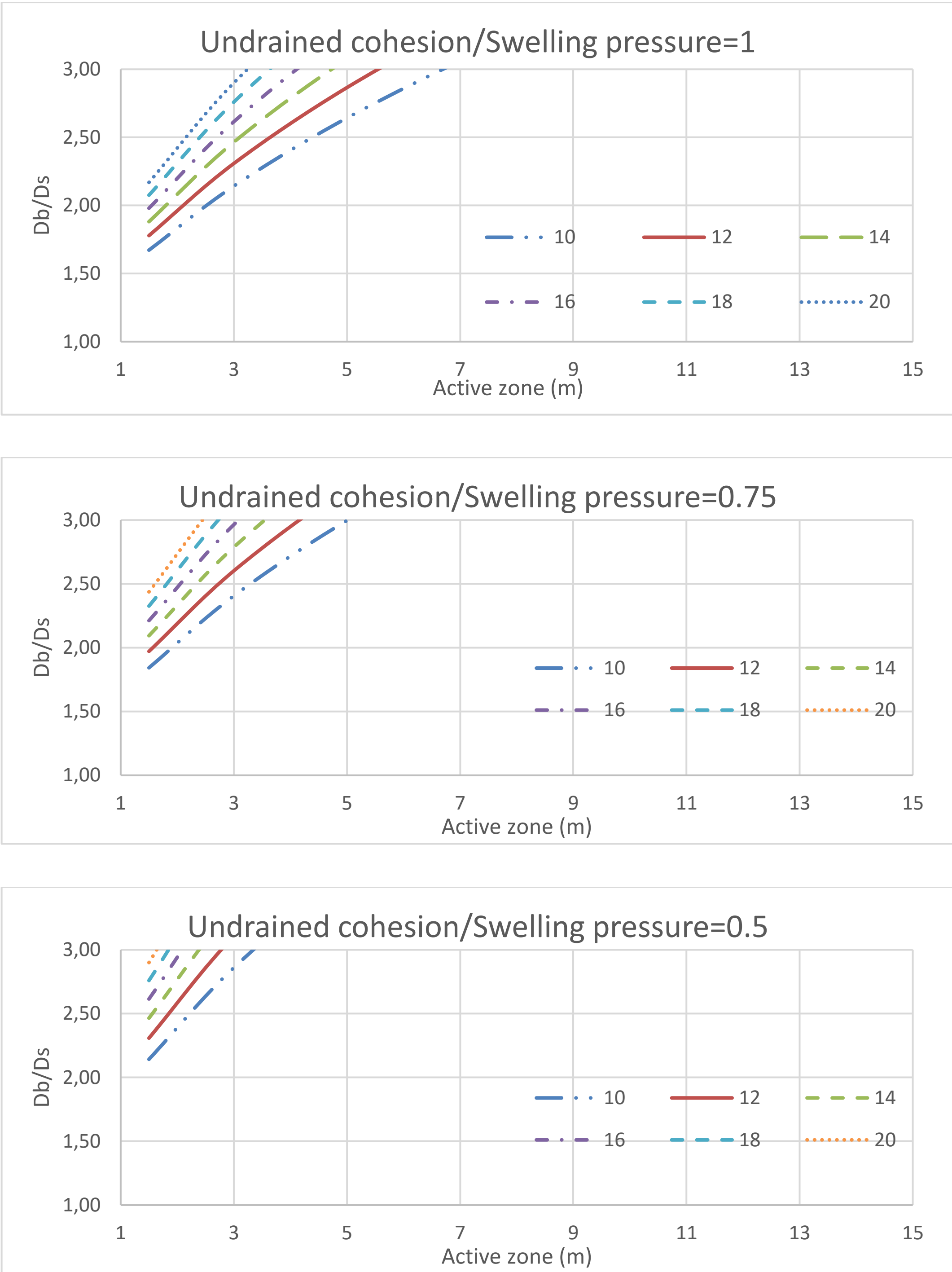

Figure 6. The diameter of belled shaft with respect to the depth of active zone, the friction angle between shaft and soil, and 0.75 m shaft diameter

4. Conclusion

The main aim of this study is that the determination of belled shaft diameter built in expansive soil layer. By all means, this process has been very complex when it is considered in some factors such as field conditions, properties of soil and shaft. For this reason, field investigation and laboratory work should be properly and carefully done prior to design of belled shaft in expansive soil layer. Some outputs obtained from this study are given below.

The diameter of shaft built in expansive soil layer should be lower value that are either 0.3 m or 0.45 m as the uplift force increases with the diameter of shaft. However, these shaft diameters may be selected as bigger values when these shaft diameter are not sufficient for design.

The depth of active zone affects the determination of diameter of belled shaft in expansive soil layer. For example, the depth of active zone is greater than 10 m, the diameter of shaft should be either lower or equal to 0.45 m.

The optimum shaft diameter was found as 0.45 m for belled shaft built in expansive soil layer.

The friction angle between shaft and soil depends on both the roughness of shaft and the index properties of soil such as density, void ratio, etc.

In conclusion, the design of belled shaft in expansive soil layer is original process due to the many factors that are related to parameters of soil, shaft, and field conditions. For this reason, the comprehensive both laboratory and field investigation should be done prior to design process.

5. Acknowledgments

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