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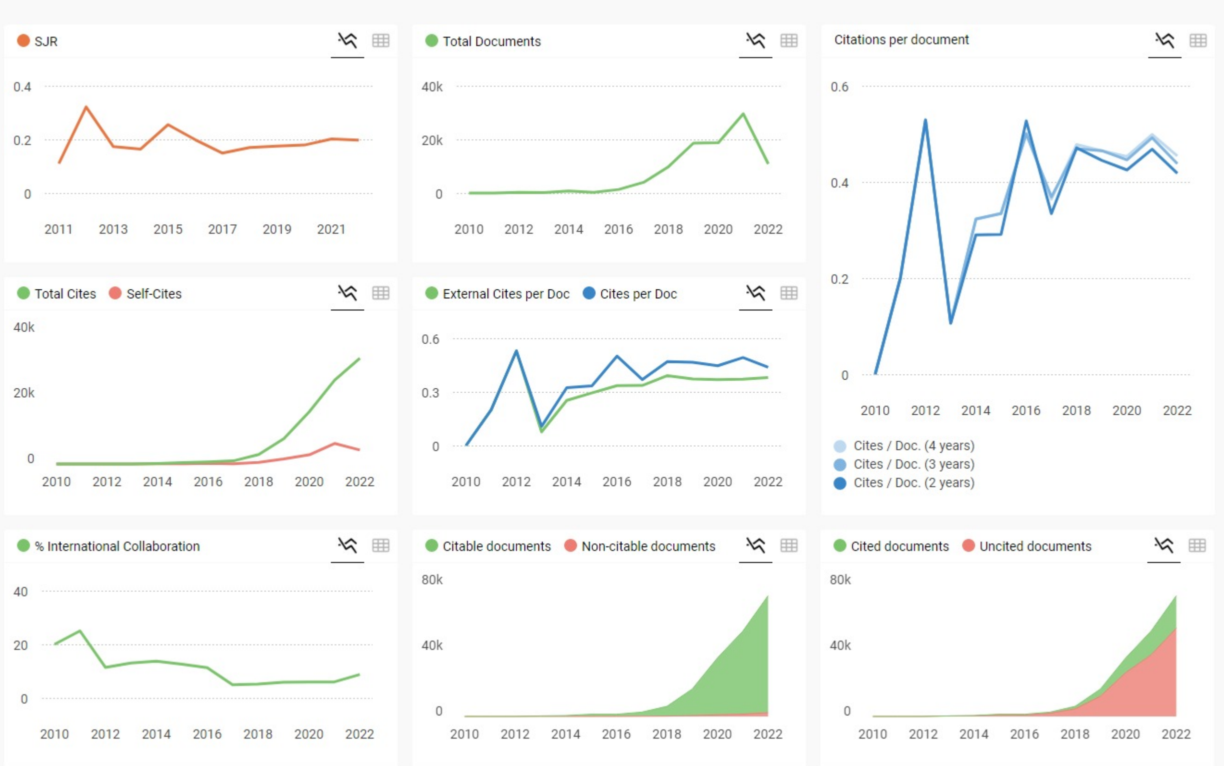

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Preface

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PREFACE

The development of Geotechnical Engineering goes together through the Case Histories considering the geological and geotechnical condition of the site. The most primitive geotechnical case histories may be dated back to 4000 BC in Egypt and until today; Geotechnical case histories have been the backbone of the sustainable growth of the infrastructures for the city and other purposes. The conference on Case Histories in Geotechnical Engineering reflects the motivations of our engineers to exchange knowledge and ideas due to the many problems that arise in the last decade. The growth of the economy of Indonesia recently is amazing, and the same for most Asian countries. Together all these factors have caused the increasing need of geotechnical advisory. The awareness of the demand for keeping up with the geotechnical technology motivated our university with series of workshop and conference about Case histories in Geotechnical Engineering. In conjunction with this conference AsRTC6 (Asian Regional Technical Committee) of GeoUrban Engineering take part in the GEOCASE 2023 Conference to enhance the meaningful of this conference theme.

Many universities, research institutions, contractors and geotechnical consultants have gained experience and knowledge which are suitable for particular site. Case histories are also of significant values for the state of the art practice. Hence the seminar is very important event for exchange of ideas and experience and for contribution all over the world..

I would like to extend my appreciation to all of you who have been travelling from far distance and specially to the Keynote Speakers and authors who made their efforts to share their knowledge and experience to the audience. This conference cannot be successful without the support of Universitas Katolik Parahyangan – Indonesia, Universiti Teknologi Malaysia – Malaysia, National Taiwan University of Science and Technology – Taiwan, National Chung Hsing University (NCHU), Taiwan, and Universiti Tun Hussein Onn – Malaysia. Also Himpunan Ahli Teknik Tanah Indonesia (HATTI), Himpunan Ahli Konstruksi Indonesia (HAKI), International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), Indonesian Ministry of Public Works and Housing (PUPR), and Institution of Civil Engineers (ICE) for the cooperation and continuous support.

Last but not least, to all members of the committee for their endless hard work and dedication, I have to acknowledge that they are the people behind the scene, for without them, this event will not come to reality.

Finally to all participants, I wish you find this conference useful and beneficial to you, and your institution.

Thank you.

Prof. Ir. Paulus P. Rahardjo, Ph.D.

Chairman of GEOCASE 2023 Conference

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Effects of Prior Footprints on the Bearing Capacity of Spudcan Foundations: A Case Study

Hendriyawan[1,2], Vebrian Anggara[1], Denny Tami[3], Indra Noer Hamdhan[4], Rildova[1,2] and Farid P. Bakti[1,2]

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Abstract
References

Abstract

A jack-up rig is a self-elevating offshore drilling platform designed for mobile operations in the marine environment. The rig is supported by 3 or 4 legs, with spudcan foundations at the end. These spudcan provide the necessary stability and load-bearing capacity for rig foundation during drilling operations. The mobile rig sometimes revisits sites where prior installation, operation, and extraction activities have resulted in identifiable footprints on the seabed. The penetration of spudcan close to, or partially overlapping, footprints shall be carefully considered because the spudcan-footprint interaction may cause a change in the ultimate vertical bearing capacity (Fv). ISO 19905-1:2016 states that the interaction between a spudcan and a footprint is expected to be minimal when the edge-to-edge distance exceeds one spudcan diameter. This paper presents the effect of existing footprints on the vertical bearing capacity of a spudcan with various spacing variations from 0.5B to 1.75B, where B is the diameter of the spudcan. A 3D finite element method (3D FEM) is employed as the primary analysis tool in analyzing the effects of footprints on layered clay soil. The 3D FEM analysis is conducted because the analytical approach outlined in ISO 19905-1:2016 does not consider the influence of the footprint on the spudcan capacity. The analysis results show that bearing capacity may reduce by more than 50% when the center-to-center distance is less than 1B. Whereas, for distances greater than 1.5B, the influence of the footprint is relatively insignificant, only reducing less than 10% of the ultimate capacity of the spudcan.

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Effects of Prior Footprints on the Bearing Capacity of Spudcan Foundations: A Case Study

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Effects of Prior Footprints on the Bearing Capacity of Spudcan Foundations: A Case Study

Hendriyawan[1,2], Vebrian Anggara[1], Denny Tami[3], Indra Noer Hamdhan[4], Rildova[1,2], and Farid P. Bakti[1,2]

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[2] Offshore Engineering Research Group, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Ganesha 10 Street, Bandung 40132, Indonesia
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Abstract. A jack-up rig is a self-elevating offshore drilling platform designed for mobile operations in the marine environment. The rig is supported by 3 or 4 legs, with spudcan foundations at the end. These spudcan provide the necessary stability and load-bearing capacity for rig foundation during drilling operations. The mobile rig sometimes revisits sites where prior installation, operation, and extraction activities have resulted in identifiable footprints on the seabed. The penetration of spudcan close to, or partially overlapping, footprints shall be carefully considered because the spudcan-footprint interaction may cause a change in the ultimate vertical bearing capacity (F_v). ISO 19905-1:2016 states that the interaction between a spudcan and a footprint is expected to be minimal when the edge-to-edge distance exceeds one spudcan diameter. This paper presents the effect of existing footprints on the vertical bearing capacity of a spudcan with various spacing variations from 0.5B to 1.75B, where B is the diameter of the spudcan. A 3D finite element method (3D FEM) is employed as the primary analysis tool in analyzing the effects of footprints on layered clay soil. The 3D FEM analysis is conducted because the analytical approach outlined in ISO 19905-1:2016 does not consider the influence of the footprint on the spudcan capacity. The analysis results show that bearing capacity may reduce by more than 50% when the center-to-center distance is less than 1B. Whereas, for distances greater than 1.5B, the influence of the footprint is relatively insignificant, only reducing less than 10% of the ultimate capacity of the spudcan.

Keywords: Spudcan, Footprint, Bearing Capacity

1. Introduction

Used extensively in the marine environment, jack-up rigs provide a stable, movable platform for offshore drilling operations. Their design, featuring 3 or 4 robust legs ending in spudcan foundations, enables the rigs to self-elevate above the sea surface. These spudcan provide the necessary stability and load-bearing capacity for rig foundation during drilling operations. During field installation, the spudcan penetrates subsoil below the seabed and is given preloading by pumping seawater into the rig's hull until it reaches a condition where the jack-up structure is balanced, stable, and rig position is not affected by waves and ocean currents.

The jack-up rig sometimes revisits sites where prior installation, operation, and extraction activities have resulted in identifiable footprints on the seabed. The penetration of spudcan close to, or partially overlapping, footprints shall be carefully considered because the spudcan-footprint interaction may cause a change in the vertical ultimate bearing capacity. These changes may reduce the rig's stability due to rapid changes in penetration depth, as shown in Figure 1.

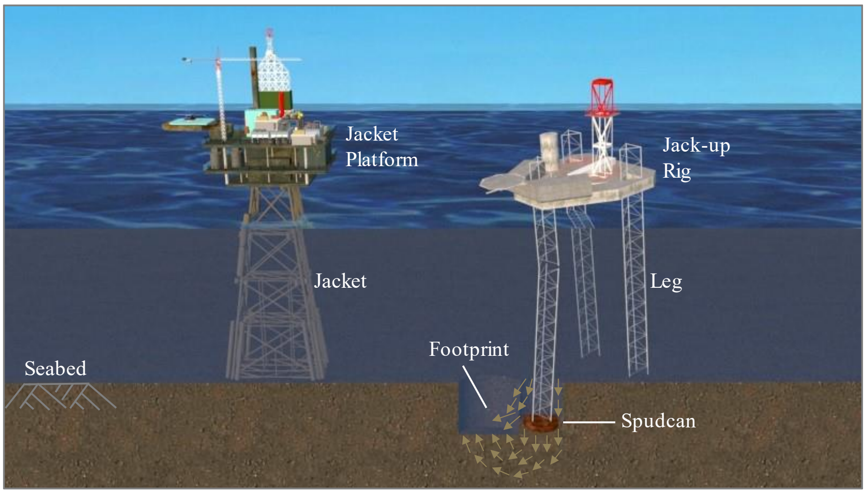

Figure 1. The failure mechanism of spudcan installation near the prior footprint.

Changes in bearing capacity due to the footprint cannot be resolved by conventional Leg Penetration Analysis (LPA) as described in ISO 19905-1:2016 [1]. The standard only states that the interaction between a spudcan and a footprint is expected to be minimal when the edge-to-edge (e-to-e) distance exceeds one spudcan diameter [1]. Therefore, a more detailed analysis, such as a numerical method, must be performed to consider the effects of old footprints on the spudcan capacity.

This paper presents the effects of the prior or existing footprint on changes in the vertical ultimate bearing capacity of the spudcan foundations. The analysis was performed by a numerical method using finite element software, namely PLAXIS 3D [2]. The effects of old footprints were analyzed by comparing the changes in the bearing capacity values with variations in the spudcan-footprint distance.

The analysis considered multi-layered cohesive soils, excluding the effects of horizontal loads. The conventional assessment following ISO 19905-1:2016 was used to check the bearing capacity without footprints. The type of spudcan used in the analysis is a circular spudcan flat base model. The depth of analysis is limited to 12 m below the seabed. The center-to-center (c-to-c) variations between spudcan and old footprints are 0.5B, 1B, 1.25B, 1.5B, and 1.75B, where B is the diameter of the spudcan. The model has also been carried out by [3], [4], [5], and [6].

2. Methodology

PLAXIS 3D analyzes the bearing capacity of the spudcan foundations based on the stress-strain curves. The undrained B option should be selected in the drainage type drop-down menu. Method B is an undrained effective stress analysis with effective stiffness parameters and undrained strength parameters. The undrained shear strength (C_u) is not updated, since this is an input parameter. The stress-strain curves resulting from the analysis of the PLAXIS 3D program need to be analyzed further to obtain the soil-bearing capacity. The bearing capacity values are determined based on the curvature shape proposed by Butler and Hoy [7] and Olgun et al. [8].

The results of PLAXIS 3D analysis produce different Mohr Failure Envelopes model for each soil type. This model is used as a first approximation of soil behaviour in general and it is recommended to use this model for a first analysis of the problem considered [2]. It will certainly be difficult to determine the maximum elastic limit conditions of the soil material. Therefore, the bearing capacity of the spudcan foundation applies the curvature concept [7], as shown in Figure 2.

3. Soil Data

3.1. Physical and mechanical properties of soils

The analyses are performed utilizing geotechnical data gathered from offshore investigation with a depth of 30 m below the seafloor. The boring test location is in shallow waters with a depth of 69.9 m MSL. The soil profile used in the analyses can be seen in Table 1.

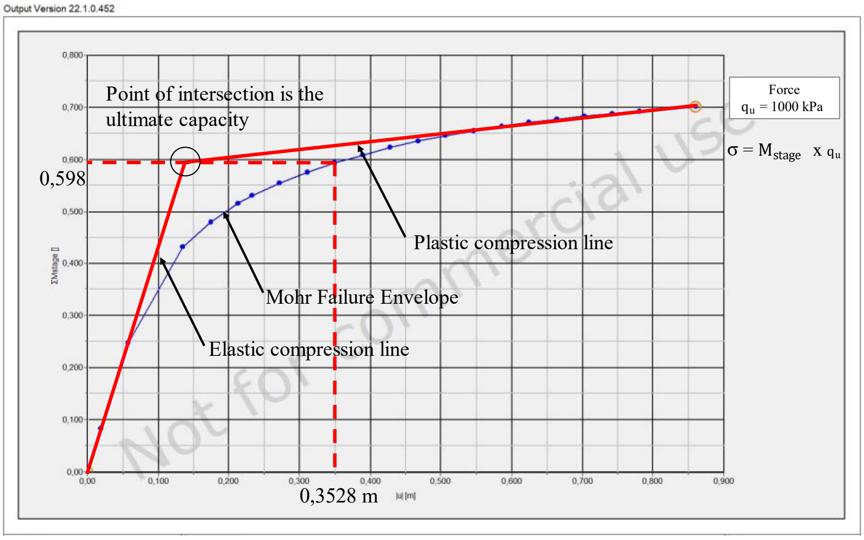

Figure 2. Curvature shape concept by [7].

Table 1. Subsoil description.

Layers	Soil Description	Penetration (m)	γ' (kN/m³)	C_u Design (kPa)	E_u vs. C_u (kPa)	E' correction (kPa)
1	Very soft to soft silty clay	0	5	3	$E_u = 200\ C_u$	522
		4		15	$E_u = 200\ C_u$	2610
2	Soft to firm silty clay	4	7	15	$E_u = 200\ C_u$	2610
		6.2		30	$E_u = 250\ C_u$	6525
3	Stiff silty clay	6.2	7	88	$E_u = 300\ C_u$	22968
		7.3			$E_u = 300\ C_u$	22968
4	Very stiff silty clay	7.3	7	125	$E_u = 350\ C_u$	38063
		9			$E_u = 350\ C_u$	38063
5	Stiff silty clay	9	7	75	$E_u = 300\ C_u$	19575
		26.3			$E_u = 300\ C_u$	19575
6	Very stiff silty clay	26.3	7	105	$E_u = 350\ C_u$	31973
		30		150	$E_u = 350\ C_u$	45675

3.2. Spudcan and footprint properties

The dimensions of spudcan foundations can vary due to the different types of jack-up rigs available from various drilling service providers. Spudcan dimensions affect the bearing capacity of the jack-up. The specification of the spudcan foundation used in the analysis is shown in Table 2. The variations of spudcan-footprint distance (center-to-center) are illustrated in Figure 3.

Table 2. Spudcan data.

Type Spudcan	Circular spudcan flat base model
Spudcan Area, A (m^2)	108.56
Equivalent Diameter, B (m)	11.76
Spudcan Volume, V (m^3)	269
Preloading for One of Legs, F_0 (MN)	40

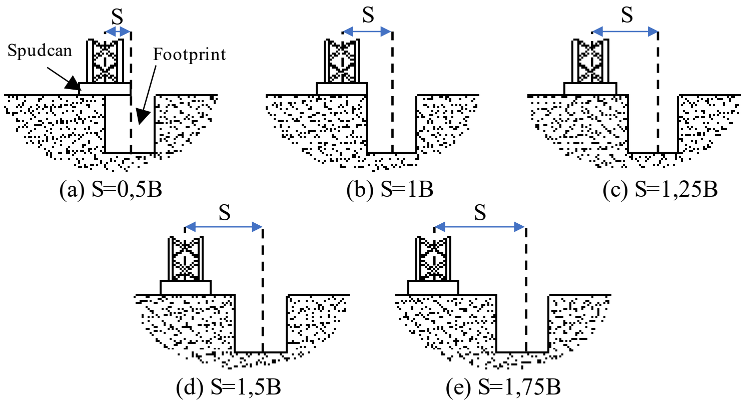

Figure 3. Spudcan-footprint distance model.

4. The Results

4.1. Soil deformation contour

The 3D-FEM model used in the analysis is shown in Figure 4. The Mohr-Coulomb (MC) model was selected as a constitutive model to simulate soil behavior. Figure 5 shows contour deformation as the effects of the old footprint on the failure planes. The figure shows that the higher deformation occurred on the side closer to the prior footprint at a distance from 0.5B to 1.5B, while at a distance of 1.75B tends to be evenly distributed between each side near the spudcan foundation. These results indicate the effects of old footprints may significantly reduce the soil stability close to the footprints.

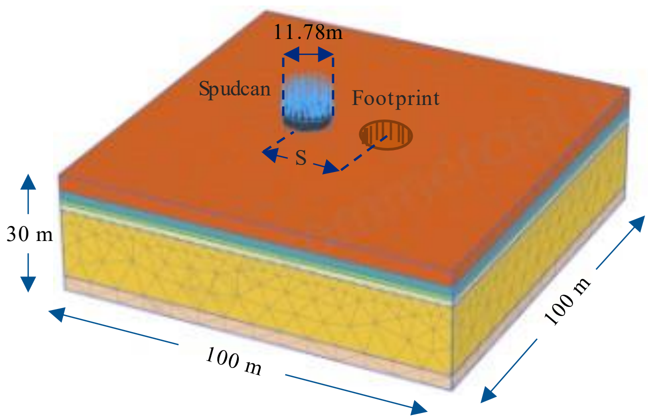

Figure 4. 3D FEM Model.

4.2. Analysis of the vertical ultimate bearing capacity influence of footprint

The analysis of the vertical ultimate bearing capacity of 3D-FEM applies the concept of curvature [7]. This study determines the ultimate bearing capacities based on the deformation of 3% of the spudcan diameters. The 3D-FEM bearing capacity analysis results can be seen in Table 3.

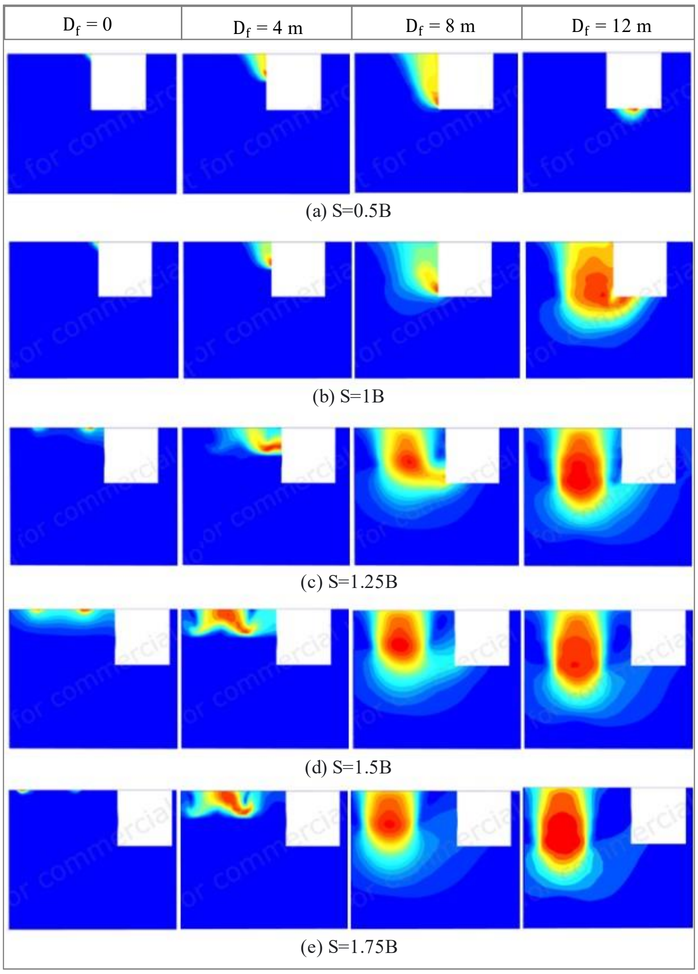

Figure 5. Soil deformation contour.

Table 3. The results of changes in the vertical ultimate bearing capacity.

Depth (m)	Vertical Ultimate Bearing Capacity										
	No Footprint	S=0.5B		S=1B		S=1.25B		S=1.5B		S=1.75B	
	Fv (MN)	Fv (MN)	Reduce (%)	Fv (MN)	Reduce (%)	Fv (MN)	Reduce (%)	Fv (MN)	Reduce (%)	Fv (MN)	Reduce (%)
0	3.22	0.56	83	1.25	61	3.39	0	3.22	0	3.39	0
1	8.09	1.12	86	2.39	70	6.13	24	7.93	2	8.14	0
2	12.20	1.79	85	3.86	68	9.05	26	12.16	0	12.70	0
3	16.72	2.73	84	5.93	65	13.35	20	16.94	0	17.37	0
4	24.43	4.30	82	9.55	61	21.44	12	25.95	0	27.14	0
5	51.57	7.94	85	17.91	65	41.69	19	48.85	5	50.21	3
6.2	61.88	16.93	73	35.28	43	51.02	18	56.45	9	57.00	8
7.3	62.97	21.56	66	42.34	33	54.50	13	58.41	7	58.62	7
8	64.92	23.81	63	46.14	29	56.78	13	59.71	8	60.25	7
9	67.85	26.46	61	51.02	25	61.88	9	62.75	8	64.05	6
10	72.19	31.09	57	57.00	21	67.09	7	67.64	6	67.85	6
11	75.99	38.37	50	66.77	12	71.65	6	71.65	6	71.65	6
12	79.79	51.57	35	79.79	0	75.45	5	75.45	5	75.45	5

The results show that a spudcan-footprint distance (c-to-c) of 0.5B typically reduces bearing capacities ranging from 35% to 86%. In comparison, the c-to-c between 1.0B and 1.25B may reduce the bearing capacity up to 70%, and for c-to-c from 1.5B and above, the reductions are less than 10%. Therefore, according to the results, the spudcan-footprint distance greater than 1.5B is considered to have a relatively minimum effect on changes in the value of the vertical ultimate bearing capacity. However, at a spudcan-footprint distance smaller than 1B, the bearing capacity values are reduced significantly; hence, the effects must be considered carefully. In addition, changes in bearing capacity may deepen the required penetration depth during preloading. The changes in penetration depths can be seen in Figure 6.

According to Figure 6, it can be seen the spudcan penetration at distances below 1.5B, the required penetration depth for 40 MN of preloading may change from 4.6 m to 11.2 m. However, the required penetration depths are relatively unaffected at distances from 1.5B and above. The detailed values in the penetration depth of the spudcan foundation can be seen in Table 4.

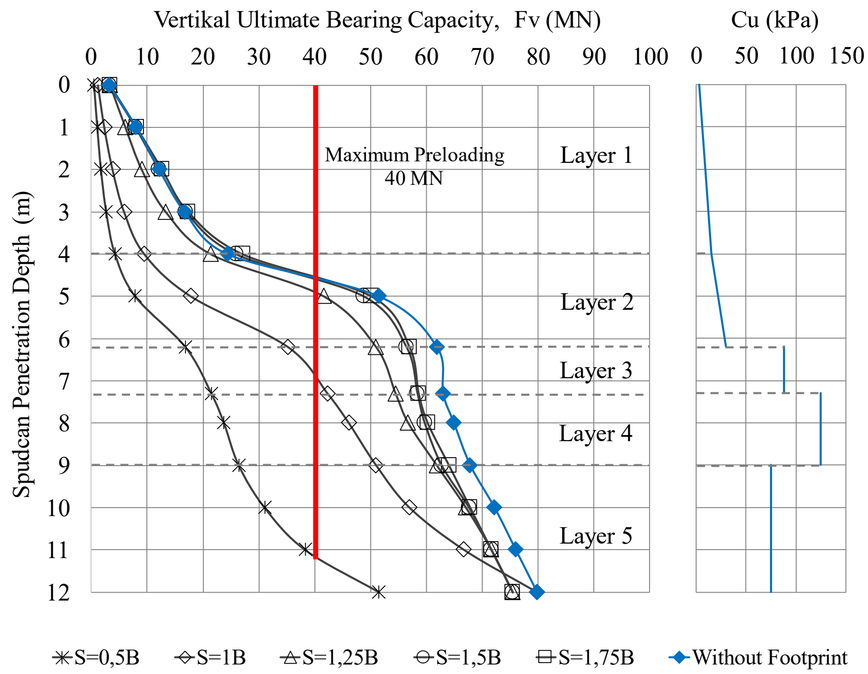

Figure 6. Changes in depth of spudcan penetration.

Table 4. Changes in spudcan penetration depth.

Preloading (MN)	Penetration Depth, D_f (m)					
	No Footprint	S=0.5B	S=1B	S=1.25B	S=1.5B	S=1.75B
10	1,50	5,30	4,00	2,25	1,50	1,50
20	3,50	6,90	5,20	4,00	3,50	3,50
30	4,25	9,80	5,80	4,50	4,25	4,25
40	4,60	11,20	6,90	4,90	4,60	4,60
50	5,00	11,90	9,00	6,00	5,00	5,00

5. Conclusions
This paper presents the effects of the prior or existing footprint on changes in the vertical ultimate bearing capacity of the spudcan foundations by using the finite element method (FEM). The analysis used a circular spudcan flat base model with the center-to-center (c-to-c) variations between spudcan and old footprints are 0.5B, 1B, 1.25B, 1.5B, and 1.75B. The analyses are conducted down to 12 m below the seabed level on the multi-layered cohesive soils.

Based on the results, the spacing between the spudcan and the existing footprints considerably influences the vertical ultimate bearing capacity. When the spudcan-footprint spacing is less than 1B, it can reduce bearing capacity by exceeding 50%. For spacings larger than 1.5B, the effect of the previous footprint is fairly negligible, reducing less than 10% of the vertical ultimate bearing capacity. In addition, changes in bearing capacity may deepen the required penetration depth during preloading. According to the results, the spudcan penetration at distances of spudcan-footprints below 1.5B, the required penetration depth for 40 MN of preloading may change from 4.6 m to 11.2 m. However, the required penetration depths are relatively unaffected at distances from 1.5B and above.

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