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Mapping of Allowable Bearing Capacity for Square and Strip Footing of Al-Khalis City

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Abstract

This research uses Geographic Information Systems (GIS) to assess the allowable bearing capacity of shallow foundations in AI-Khalis District, located along the Diyala River about 20 kilometres northeast of Baghdad within the Diyala Governorate. From 12 exploration sites, each containing several boreholes, around 35 test records were gathered at different depths. The database contained unit weights, soil classification, and results from the Standard Penetration Test (SPT). The correlation and modification of the SPT results were used to calculate the undrained shear strength (Cu). Subsequently. Terzaghi's equations were used to determine the permissible soil bearing capacity for two types of foundations: square (B= 1.5 m) and strip (B 1 m) at excavation depths of 1 and 2 metres. The data were then collected in an Excel file and entered into the Geographic Information System (GIS) to produce maps. The results revealed a significant variation in the permissible soil bearing capacity across different depths, i.e., it gradually increases with depth. This study aims to provide geotechnical engineers with an initial view of the type of foundation and the number of layers.

Keywords: GIS, Bearing Capacity, Footing, SPT.

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1. Introduction

The most important factor in geotechnical engineering is the soil's bearing capacity. Soil bearing capacity varies from one soil type to another. Rocky soils have a high bearing capacity, while clayey and sandy soils have a lower bearing capacity. Due to the application of various computer tools, geotechnical site studies have changed in recent years. Geographic Information Systems (GIS) like ArcGIS Pro have made it possible for engineers to comprehend and assess soil data spatially via the generation of themed maps that represent variations in soil features across large areas [1].

In Fallujah, geographic information systems (GIS) were employed, with corrected SPT data from 149 boreholes to identify the bearing capacity of shallow (qu) and undrained shear strength (Su) at various depths [2]. In Eskisehir, Turkey, calculate the allowable bearing capacity by using GIS. Terzaghi's equation and SPT measurement down to a depth of 5 metres [3]. A study was conducted in Basra by using the ArcGIS 10.5 program to generate three-dimensional maps to estimate the strength and compressive strength of the soil. The study was conducted on 164 bodies up to 12 meters [4]. In Basra, using SPT data and GIS techniques, a study was conducted to create thematic maps of soil bearing capability for shallow foundations [5].

In the Philippines, researchers proposed maps of Butuan's soil bearing capacity using SPT data. Applications in the city used different interpolation techniques such as IDW, Kriging, and Spline [6]. In Najaf, a study was executed using interpolation methodologies such as IDW and Kriging. Within

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GIS, these methods were investigated to determine the most precise method for estimating soil bearing capacity [7]. Najaf and Kufa. More than 460 boreholes were examined for maps of allowed bearing capacity at shallow depths, which were developed using GIS-based [8]. The value and limitations of SPT-based design techniques have been checked through evaluations of their accuracy in forecasting the performance of shallow foundations [9].

To support greater foundation planning in seismically unstable regions, the Morang District in Nepal has been studied for variances in soil bearing capacity [10]. In Goa, India, GIS-based mapping was used to improve regional planning by determining safe bearing capacity values at several locations [11]

In Jakarta, researchers used N-SPT values to develop bearing capacity and hard layer depth maps. Illustrating how geotechnical investigation and spatial analysis may be combined [12]. The analytical foundation design background, including the frequently used bearing capacity equation in application, is provided by classic works like Bowles (1996) [13]. According to Atkinson (2017), knowledge of the fundamentals of soil mechanics is essential for evaluating the behaviour of foundations and geotechnical test results [14]. According to Japan by Shioi and Fukui (1982), the use of N-value in foundation design was first. And they continue to affect the relationship between SPT data and bearing capacity [15].

In Erbil, a study was also performed using Artificial Neural Networks (ANN) integrated with Geographic Information Systems (GIS) to evaluate the geotechnical features of soil in Erbil [16]. By integrating SPT data with geographic information systems, accurate soil bearing capacity maps can be created. Due to limited well coverage, this research seeks to fill these gaps by using ArcGIS Pro with SPT field experiments to create reliable soil bearing capacity maps.

2. Methodology

2.1 Description of Region

The Diyala Governorate, which is located further to the north, extends to an area that amounts to 17,617 km^2, or over 4% of all of Iraq. The Diyala Governorate lies between latitudes 31°45' north and 33°30' north and longitudes 44°30' east and 46°45' east. The province's northern boundary with Iran is home to mountain ranges. The Diyala Governorate's geographical composition is very Diyala Governorate, approximately 55 km from Baghdad, which is the capital of Iraq. It is the district of Al-Khalis's centre location, as seen in Fig. 2. To determine the allowable bearing capacity of clay soil, a large quantity of data was gathered, such as soil classification, cohesion, internal friction angle, unit weight, and SPT.

The stipulated methodological processes were followed in this research, in addition to the results of on-site evaluations, mainly the SPT inspections of sizable portions of the governorate, as data that work towards generating geotechnical maps varied and includes plains, which constitute the vast majority of the governorate and fall along the banks of the Diyala River. Valleys: The Nar Valley and the Diyala River Valley are situated in the southern region of the governorate, as shown in Fig. 1. Khalis's city is located in the northwest of Baghdad.

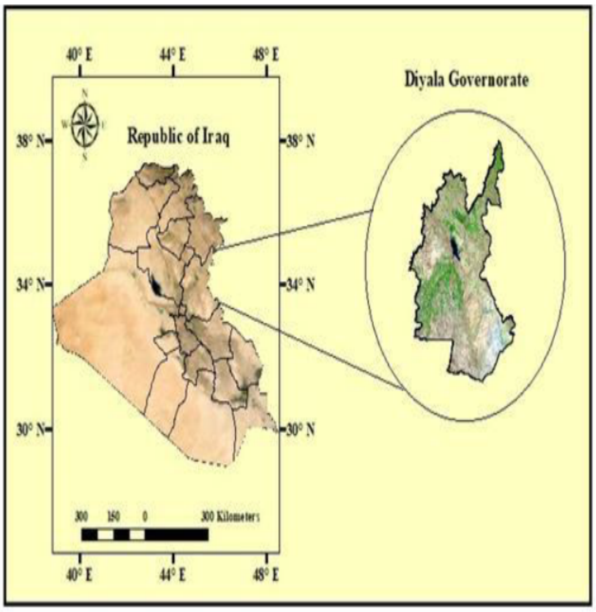

Fig. 1 The study area, Diyala governorate, of the geographical location [17].

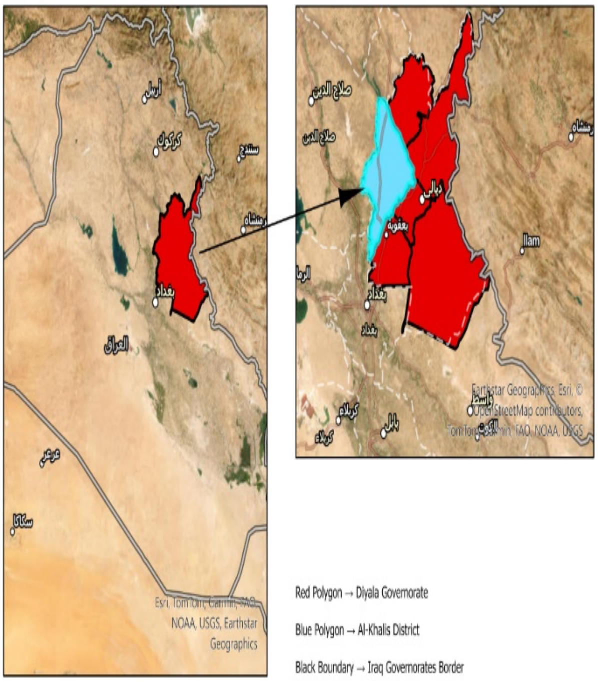

Fig. 2 City of AI-Khalis, the centre of Diyala Governorate (prepared by the author using ArcGIS Pro.)

2.2 Data Collection

Reports from geotechnical investigations were gathered from various locations in the Al-Khalis District. Standard Penetration Test (SPT) results from boreholes, as well as mechanical and physical soil characteristics, were included in these geotechnical investigation reports.

2.3 Data Processing

Overburden and hammer efficiency modifications were applied to the raw SPT results. To estimate soil cohesion (Cu). The corrected values were then associated with undrained shear strength (Cu) using empirical relationships from Bowles (1996). The undrained shear strength (Cu) was estimated indirectly based on the Standard Penetration Test (SPT). The number of blows (N) was corrected to N70 using the corrected N70 values. The corresponding unconfined compressive strength (qu) for each N70 value was determined based on the relationship proposed in Bowles (1996), as shown in Table 1 for clay soils. The unconfined compressive strength (qu) was then divided by two to obtain the undrained shear strength (Cu) [13].

Table 1: The standard penetration test (SPT), N-value used to evaluate the bearing capacity [13].

Consistency	Description	N_{70}	$q_{(u)}$ kPa	Remakes
Vary soft	NC-Young clay	0-2	<25	Squishes between fingers when squeezed
Soft	NC-Young clay	3-5	25-50	Very easily deformed by squeezing
Medium	NC-Young clay	6-9	50-100	-
Stiff	Increasing OCR-Aged cemented	10-16	100-200	Hard to deform by hard squeezing
Very stiff	Increasing OCR-Aged cemented	17-30	200-400	Very hard to deform by hand-squeezing
Hard	Increasing OCR-Aged cemented	>30	>400	Nearly impossible to deform by hand

2.4 Calculations of Bearing Capacity

The ultimate and allowable capacities of shallow foundations were determined using the Terzaghi bearing capacity equations (1943). At a depth of Df = 1.0 m, strip footings (B = 1.0 m) and square footings (B = 1.5 m) were both taken into consideration. The effective unit weight (γeff) was used to account for the impact of groundwater. Using a factor of safety of 3, the allowable bearing capacity (Qall) was determined.

Bearing Capacity Equations (Terzaghi)

(1) Bearing Capacity Equation for Square Footing:

$$q_u = 1.3\, c\, Nc + q\, Nq + 0.4\, \gamma\, B\, N\gamma \quad (1)$$

(2) Bearing Capacity Equation for Strip Footing:

$$q_u = c\, Nc + q\, Nq + 0.5\, \gamma\, B\, N\gamma \quad (2)$$

(3) Factor of Safety:

F.S = 3

(4) Allowable Bearing Capacity:

$qall = q_u / F.S$

Where:

Quilt = Ultimate bearing capacity (kPa)

C = Cohesion of soil (kPa)

B = Width of foundation (m)

q = γ. Df

γ = Unit weight of soil ($KN/m^{3)}$

Df = Depth of foundation (m)

Nc, Nq, Nγ = Bearing capacity factors

2.5 Software

This essay talks about GIS software as a way to store, retrieve, show, organize, and study several types of

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geographical information. This file shows the coordinates and names of the sites that are being investigated. Additionally, it includes every table with the data utilized for the analysis. The ArcGIS Pro program then used this database to produce and investigate maps using a set of tools. In the end, the GIS pro was used to produce the geotechnical map of Diyala soil characteristic features.

2.6 Inverse Distance Weighting (IDW)

A reliable, fast, deterministic interpolator is IDW. There are not many choices to be made about model parameters. An interpolated surface can be seen first, thanks to its excellent length. Despite this, prediction error rates are recorded, and IDW might create "bullseyes" in data locations [18]. Based on a specific collection of measurements of this parameter at different places, the two-dimensional interpolation seeks to determine the parameter in non-scaled locations. Any characteristic of the soil is expressed by the parameter. Any website can use the IDW algorithm, which is based on equations (3) and (4) [19]

$$\mathrm{oldz}_{(x)} = \frac{\sum_{i=1}^{n} w_i z_i}{\sum_{i}^{n} z_i} \quad (3)$$

$$w_i = |x - x_i| \quad (4)$$

2.7 Cross-Validation

The IDW model was employed to assess the correctness of the spatial model in creating soil bearing capacity maps by applying the cross-validation method. This approach treats each test point as an unknown and removes it one at a time. The leftover points are then used to recalculate it. The inaccuracy for each point is then determined by comparing the estimated value with the actual value. According to the verification results, there was no error because the mean squared error (MSE) was nearly zero. Geometrically acceptable limits were met by the root-mean-square error (RMSE).

3. Results and Discussion

Based on the values listed in Table 2, and with reference to the spatial distribution shown in Figure. 3 the allowable bearing capacity in tons/m² for a square footing in the Al-Khalis region. It is clear from the figure that the north region of Al-Khalis has an allowable bearing capacity ranging between 5-6.5 tons/m², while the south region has a narrow area ranging between 3-5 tons/m². The highest values of allowable bearing capacity were noticed in the lower narrow region near the border between Baqubah and Maqdadiya city, where the values reached 9-11 tons/m². The centre of Al-Khalis's city has an allowable bearing capacity between 4-4.5 tons/m².

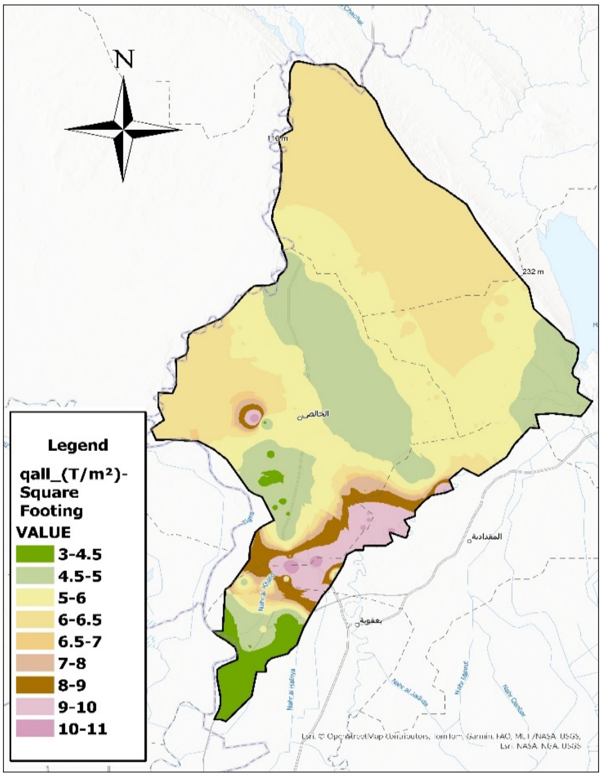

Fig. 3 The allowable bearing capacity in tons/m² for a square footing of the Al-Khalis region (at a depth of 1m).

Based on the values listed in Table 3 and with reference to the spatial distribution shown in fig. 4, the allowable bearing capacity of the strip is illustrated. Part of Al-Khalis has an allowable bearing capacity range of 5-6 tons/m², while the southern region has fluctuating values and changes clearly with the ranges of 3-4.5 tons/m² and 5-7 tons/m². The maximum values of allowable bearing capacity are located in narrow areas in the west direction, with 9-11 tons/m². The allowable bearing capacity of the centre of Al-Khalis's city is 6-8 tons/m².

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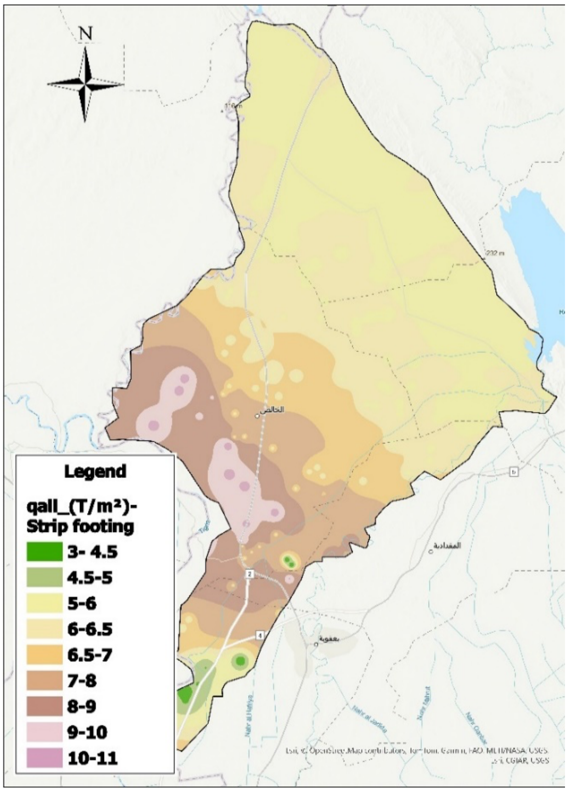

Fig. 4 The allowable bearing capacity in tons/m² for strip footing of Al-Khalis's region (at a depth of 1m).

Based on the values listed in Table 4 and with reference to the spatial distribution shown in fig. 5 depicts the allowable bearing capacity of a square footing for a depth of excavation of DF = 2 m in Al-Khalis's region is depicted. The north and middle of Al-Khalis's region have allowable bearing capacity ranges from 6 to 7.5 tons/m², while the largest values of allowable bearing capacity reached 4 to 6 tons/m² and 8 to 10 tons/m² in small areas.

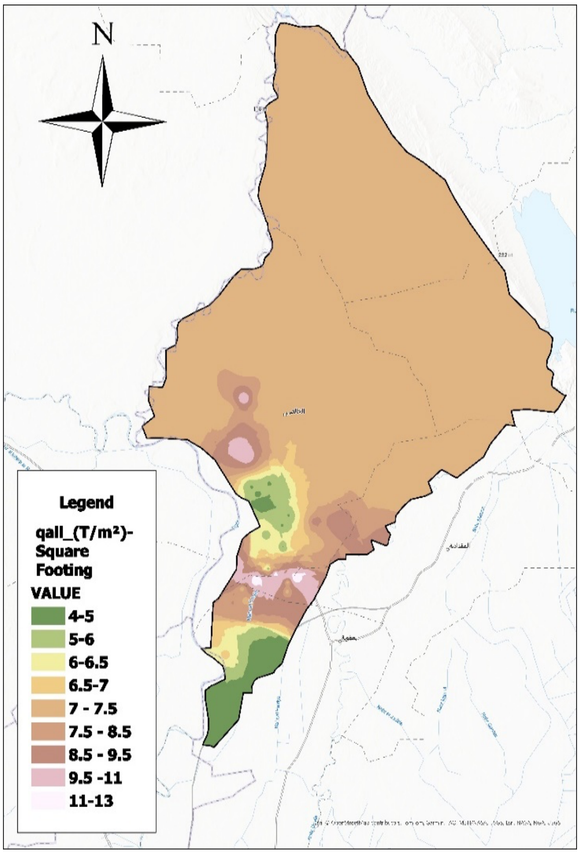

Fig. 5 The allowable bearing capacity in tons/m² for a square footing of the Al-Khalis region (at a depth of 2m).

Based on the values listed in Table 5 and with reference to the spatial distribution shown in fig. 6 illustrates the allowable bearing capacity of the Al-Khalis region for a strip footing of depth DF = 2 m is illustrated. It is clear from this figure that the north and east parts have an allowable bearing capacity of 6 to 7.5 tons/m², while the west direction reached 9.5 to 11 tons. The small area in the south has an allowable bearing capacity equal to 4 to 6 tons/m². The standard penetration test (SPT) values in this study were similar for each well. However, a slight increase in the allowable soil bearing capacity was observed at the second depth for both square and strip foundations. The additional depth contributes to a small increase in bearing capacity due to the increased lateral stress of the soil, even with similar soil N values.

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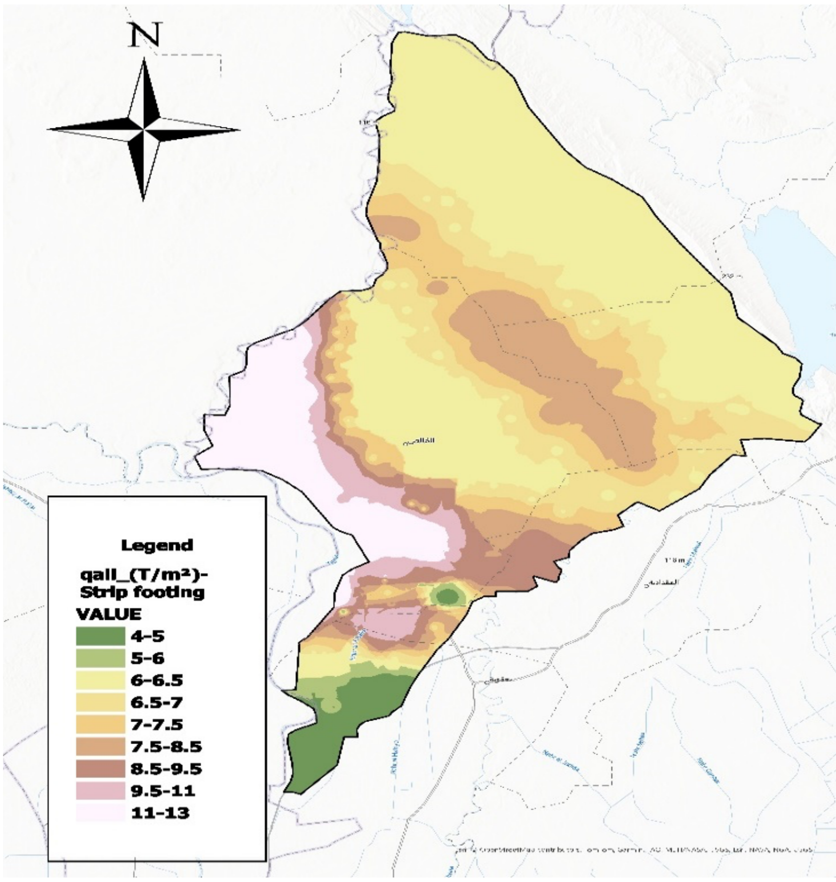

Fig. 6 The allowable bearing capacity in tons/m² for strip footing of Al-Khalis's region (a depth of 2m)

Table 2: Summary of bearing capacity parameters at different depths for the square footing (SPT-based calculations)

Site	Depth(m)	SPT	q_u (kPa)	Cu (kPa)	Ø	γ(kN/m³)	q_{all} (T/m²)
BH1	0-1	4	37.5	18.75	0	17.2	5
BH2	0-1	3	25	12.5	0	17.12	3
BH3	0-1	5	50	25	0	17.31	6
BH4	0-1	10	100	50	0	17	13
BH5	0-1	6	50	25	0	18.3	6
BH6	0-1	4	37.5	18.75	0	19.85	5
BH7	0-1	5	50	25	0	19.21	6
BH8	0-1	6	50	25	0	19.12	6
BH9	0-1	6	50	25	0	19.82	7
BH10	0-1	5	50	25	0	18.62	6
BH11	0-1	5	50	25	0	20.35	7
BH12	0-1	8	83.3	41.67	0	17.8	11
BH13	0-1	8	83.3	41.67	0	20.2	11
BH14	0-1	10	100	50	0	19.84	13
BH15	0-1	8	83.3	41.67	0	20.2	11
BH16	0-1	8	83.3	41.67	0	19.84	11
BH17	0-1	6	50	25	0	17.71	6
BH18	0-1	6	50	25	0	16.22	7
BH19	0-1	7	66.67	33.3	0	17.21	9
BH20	0-1	5	50	25	0	14.67	6

BH21	0-1	5	50	25	0	17.3	7
BH22	0-1	4	37.5	18.75	0	17	5
BH23	0-1	10	100	50	0	17.44	13
BH24	0-1	3	25	12.5	0	19.84	3
BH25	0-1	5	50	25	0	18	7
BH26	0-1	7	66.67	33.3	0	18.8	9
BH27	0-1	4	37.5	18.75	0	17.3	5
BH28	0-1	6	50	25	0	14.7	6
BH29	0-1	5	50	25	0	18	7
BH30	0-1	5	50	25	0	20.45	7
BH31	0-1	6	50	25	0	17.85	7
BH32	0-1	6	50	25	0	18.5	7
BH33	0-1	5	50	25	0	18.9	7
BH34	0-1	5	50	25	0	18.5	7
BH35	0-1	3	25	12.5	0	19	3

Table 3: Summary of bearing capacity parameters at different depths for the square footing (SPT-based calculations).

Site	Depth(m)	SPT	q_u (kPa)	Cu (kPa)	Ø	γ(kN/m^3)	q_{all} (T/m^2)
BH1	1-2	4	37.5	18.75	0	17.2	5
BH2	1-2	3	25	12.5	0	17.12	4
BH3	1-2	5	50	25	0	17.31	7
BH4	1-2	10	100	50	0	17	13
BH5	1-2	6	50	25	0	18.3	7
BH6	1-2	4	37.5	18.75	0	19.85	5
BH7	1-2	5	50	25	0	19.21	7
BH8	1-2	6	50	25	0	19.12	7
BH9	1-2	6	50	25	0	19.82	7
BH10	1-2	5	50	25	0	18.62	7
BH11	1-2	5	50	25	0	20.35	7
BH12	1-2	8	83.3	41.67	0	17.8	11
BH13	1-2	8	83.3	41.67	0	20.2	11
BH14	1-2	10	100	50	0	19.84	13
BH15	1-2	8	83.3	41.67	0	20.2	11
BH16	1-2	8	83.3	41.67	0	19.84	11
BH17	1-2	6	50	25	0	17.71	7
BH18	1-2	6	50	25	0	16.22	7
BH19	1-2	7	66.67	33.3	0	17.21	9
BH20	1-2	5	50	25	0	14.67	6
BH21	1-2	5	50	25	0	17.3	7
BH22	1-2	4	37.5	18.75	0	17	5
BH23	1-2	10	100	50	0	17.44	13
BH24	1-2	3	25	12.5	0	19.84	4
BH25	1-2	5	50	25	0	18	7
BH26	1-2	7	66.67	33.3	0	18.8	9
BH27	1-2	4	37.5	18.75	0	17.3	5
BH28	1-2	6	50	25	0	14.7	7
BH29	1-2	5	50	25	0	18	7
BH30	1-2	5	50	25	0	20.45	7
BH31	1-2	6	50	25	0	17.85	7

BH32	1-2	6	50	25	0	18.5	7
BH33	1-2	5	50	25	0	18.9	7
BH34	1-2	5	50	25	0	18.5	7
BH35	1-2	3	25	12.5	0	19	4

Table 4: Summary of bearing capacity parameters at different depths for the strip footing (SPT-based calculations)

Site	Depth(m)	SPT	q_u (kPa)	Cu (kPa)	Ø	γ(kN/m^3)	q_{all} (T/m^2)
BH1	0-1	4	37.5	18.75	0	17.2	4
BH2	0-1	3	25	12.5	0	17.12	3
BH3	0-1	5	50	25	0	17.31	5
BH4	0-1	10	100	50	0	17	10
BH5	0-1	6	50	25	0	18.3	12
BH6	0-1	4	37.5	18.75	0	19.85	13
BH7	0-1	5	50	25	0	19.21	5
BH8	0-1	6	50	25	0	19.12	5
BH9	0-1	6	50	25	0	19.82	5
BH10	0-1	5	50	25	0	18.62	5
BH11	0-1	5	50	25	0	20.35	12
BH12	0-1	8	83.3	41.67	0	17.8	8
BH13	0-1	8	83.3	41.67	0	20.2	13
BH14	0-1	10	100	50	0	19.84	10
BH15	0-1	8	83.3	41.67	0	20.2	8
BH16	0-1	8	83.3	41.67	0	19.84	8
BH17	0-1	6	50	25	0	17.71	5
BH18	0-1	6	50	25	0	16.22	5
BH19	0-1	7	66.67	33.3	0	17.21	7
BH20	0-1	5	50	25	0	14.67	5
BH21	0-1	5	50	25	0	17.3	5
BH22	0-1	4	37.5	18.75	0	17	4
BH23	0-1	10	100	50	0	17.44	10
BH24	0-1	3	25	12.5	0	19.84	3
BH25	0-1	5	50	25	0	18	5
BH26	0-1	7	66.67	33.3	0	18.8	7
BH27	0-1	4	37.5	18.75	0	17.3	4
BH28	0-1	6	50	25	0	14.7	5
BH29	0-1	5	50	25	0	18	5
BH30	0-1	5	50	25	0	20.45	5
BH31	0-1	6	50	25	0	17.85	6
BH32	0-1	6	50	25	0	18.5	6
BH33	0-1	5	50	25	0	18.9	5
BH34	0-1	5	50	25	0	18.5	5
BH35	0-1	3	25	12.5	0	19	3

Table 5: Summary of bearing capacity parameters at different depths for the strip footing (SPT-based calculations).

Site	Depth(m)	SPT	q_u (kPa)	Cu (kPa)	Ø	γ(kN/m³)	q_{all} (T/m²)
BH1	1-2	4	37.5	18.75	0	17.2	4
BH2	1-2	3	25	12.5	0	17.12	3
BH3	1-2	5	50	25	0	17.31	5
BH4	1-2	10	100	50	0	17	10
BH5	1-2	6	50	25	0	18.3	12
BH6	1-2	4	37.5	18.75	0	19.85	13
BH7	1-2	5	50	25	0	19.21	5
BH8	1-2	6	50	25	0	19.12	5
BH9	1-2	6	50	25	0	19.82	5
BH10	1-2	5	50	25	0	18.62	5
BH11	1-2	5	50	25	0	20.35	12
BH12	1-2	8	83.3	41.67	0	17.8	9
BH13	1-2	8	83.3	41.67	0	20.2	13
BH14	1-2	10	100	50	0	19.84	10
BH15	1-2	8	83.3	41.67	0	20.2	9
BH16	1-2	8	83.3	41.67	0	19.84	9
BH17	1-2	6	50	25	0	17.71	5
BH18	1-2	6	50	25	0	16.22	5
BH19	1-2	7	66.67	33.3	0	17.21	7
BH20	1-2	5	50	25	0	14.67	5
BH21	1-2	5	50	25	0	17.3	5
BH22	1-2	4	37.5	18.75	0	17	4
BH23	1-2	10	100	50	0	17.44	10
BH24	1-2	3	25	12.5	0	19.84	3
BH25	1-2	5	50	25	0	18	5
BH26	1-2	7	66.67	33.3	0	18.8	7
BH27	1-2	4	37.5	18.75	0	17.3	4
BH28	1-2	6	50	25	0	14.7	5
BH29	1-2	5	50	25	0	18	5
BH30	1-2	5	50	25	0	20.45	6
BH31	1-2	6	50	25	0	17.85	6
BH32	1-2	6	50	25	0	18.5	6
BH33	1-2	5	50	25	0	18.9	5
BH34	1-2	5	50	25	0	18.5	5
BH35	1-2	3	25	12.5	0	19	3

4. Conclusions

The following points are drawn from this study.

1. GIS is an effective tool that may be used to predict the preliminary bearing capacity of any region.
2. The highest value of allowable bearing capacity is located in a narrow region lying near Baquba city and Al-Maqdadiya city, and reached 9-11 tons/m² for square forging.
3. Values of allowable bearing capacity for strip footing are slightly more than square forging.
4. Generally, a preliminary assessment of bearing capacity may be used for any project before the design stage.
5. The increase in depth of square and strip footing leads to an increase in allowable bearing capacity by 0.80 tons/m².

Conflict of interest

The authors declare that there is no conflict of interest.

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