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GIS based Estimation of Soil Bearing Capacity using Borehole and Geophysical Data

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***Abstract*— One of the most critical parameters of an engineering foundation is the bearing capacity of soil (i.e., soil bearing capacity). Having an accurate estimate of the soil bearing capacity of the ground is necessary for designing civil engineering structures safely and efficiently. Traditional methods of determining the soil bearing capacity of the ground involved performing borehole investigations and laboratory tests. Although these methods are reliable, they take excessive amounts of time to obtain results (i.e., borehole investigations) and are expensive due to the equipment and personnel required. Furthermore, soil bearing capacity values will frequently not be obtainable in many areas of a project's site.**

Geographic Information Systems (GIS) provide an efficient means of storing, manipulating, and analyzing spatially referenced data. By integrating borehole and geotechnical data with GIS software, an approximate value of soil bearing capacity can be estimated at locations that have not been tested for this parameter using techniques for interpolating between spatial data points. This study used QGIS as a GIS tool to develop a GIS-based map showing a distribution of soil bearing capacity in the study area. This was accomplished by collecting soil bearing capacity data, creating spatial datasets, interpolating soil bearing capacity data, and creating visualizations of the results.

The final product from this study will be a GIS-generated map of the location of low, medium, and high soil bearing capacities that can be used as a basis for preliminary planning of foundations. Use of this map will minimize the time and cost associated with further soil investigation at the beginning of future projects and will aid civil engineers in making good decisions as they manage their projects.

***Keywords*— Soil Bearing Capacity, GIS, QGIS, Borehole Data, Spatial Interpolation, Geotechnical Engineering.**

I. Introduction

Soil bearing strength is one of the critical parameters used in foundation design (i.e., isolated footings, raft foundations, pile foundations). If SBC (soil bearing capacity) is estimated too high or too low, the structure could fail, differentially settle over an extended period, or cost more to build. Traditional methods of estimating SBC include field investigations such as boreholes, Standard Penetration Tests (SPTs), and testing soil samples in the laboratory. Field and laboratory testing methods provide accurate SBC data at a particular location; however, testing is usually only performed at a limited number of selected locations due to limitations with time, money and access. As a result, SBC data will not be available at most locations within the entire project area.

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GIS is a powerful tool that enables spatial analysis of data and visualization of results. GIS enables the ability to combine spatial data and engineering properties of soils to analyze how those properties change spatially. By creating an algorithm using GIS, we can produce SBC estimates for untested locations by using geographic interpolation techniques based on available SBC estimates from the near-by locations.
This research will utilize GIS technologies to estimate and map SBC throughout the Study Area utilizing existing borehole and geotechnical data. The prepared SBC maps will facilitate future researches to identify areas of interest in regards to soil stability in order to evaluate and determine which method(s) would provide the best solution for use in design and construction processes.

II. Literature Review

Several researchers have studied the application of GIS and geotechnical data for subsurface modeling and soil bearing capacity estimation. A brief review of relevant studies is presented below.

A. Study by Civelekler et al. (2023)

Civelekler et al. illustrated using GIS to create a 3D subsurface model from geophysical and borehole data. They integrated several different types of borehole and geophysical data into a GIS system to identify the spatial variation of soil properties. The authors pointed out that just having boreholes is usually not enough to accurately describe the subsurface conditions.
The study showed that using GIS for visualizing the soil layers enhances the ability of the engineer to make more informed decisions about subsurface conditions. Overall, this study showed that GIS is an excellent tool for preliminary assessments of sites and for characterizing the subsurface in places where there is little or no borehole data to use for those assessments.

B. Study published in KSCE Journal of Civil Engineering

The paper published in the KSCE Journal highlighted the need to integrate geotechnical investigation data with spatial analysis techniques. The authors applied GIS-based interpolation techniques to estimate soil properties between boreholes. The findings indicated that GIS-based estimation can produce a continuous spatial distribution of soil properties, which is not easily possible with conventional estimation techniques.
The paper also highlighted the limitations in terms of data density and accuracy, indicating that GIS-based estimation results are primarily useful for preliminary planning purposes. The paper thoroughly supported the application of GIS as a decision-support system in geotechnical engineering.

C. Study on GIS-Based Soil Bearing Capacity Mapping

Numerous Studies have been conducted in which GIS-Based mapping of SBC have been performed by interpolating commonly available data through borehole sampling methods using GIS-based methods. Most studies reported that Spatial Interpolating Methods such as IDW and Kriging are usually used to predict SBC at sites that have not been tested for SBC.
The studies showed that GIS Based SBC maps assist with identifying Weak Soil Areas and also identifying Good Soil Areas for shallow foundations. It was concluded by the authors in the studies that GIS substantially decreases the amount of time and money spent in comparison to Traditional methods of Foundation Design at the initial Planning or Preliminary stage of the construction process.

D. Study on Integration of Borehole and Geophysical Data

It has been observed in previous studies that the integration of borehole and geophysical data helps in better subsurface modeling.

TABLE I: SUMMARY OF PREVIOUS RESEARCH STUDIES

Sr. No.	Author / Year	Data Used	Methodology	Key Findings
1	Civelekleret al. (2023)	Borehole & Geophysical data	GIS-based 3D subsurface modeling	Improved visualization and understanding of subsurface conditions
2	KSCE Journal Study	Borehole data	GIS interpolation techniques	Continuous spatial estimation of soil properties
3	Various Researchers	SBC & borehole data	IDW and Kriging methods	Effective preliminary SBC mapping
4	Previous Geotechnical Studies	Borehole + geophysical data	Integrated GIS analysis	Reduced uncertainty in subsurface characterization

Borehole data helps in providing precise point data, whereas geophysical surveys help in providing continuous subsurface information. GIS serves as a common platform for the effective integration of both types of data. The authors have concluded that the integrated GIS-based subsurface models help in increasing the reliability and decreasing the uncertainty of geotechnical analysis.
It is evident from the above-mentioned studies that the GIS-based analysis has a crucial role in subsurface modeling and soil bearing capacity calculation. Most authors have agreed that GIS helps in improving visualization, facilitating spatial analysis, and aiding in the preliminary stage of decision-making. But all authors have stressed that GIS-based analysis should not replace the need for detailed field investigations.

III. Study Area

The current research study was conducted in a selected study area that had a sufficient and reliable source of soil investigation and borehole data available to evaluate. The study area's selection is critical within a GIS-based analysis because the results' accuracy is dependent on the quality and spatial distribution of the input data.
The study area is representative of an urban/semi-urban area with an increasing number of construction projects. The ongoing development of infrastructure creates a need for properly assessing the soil bearing capacity of the area to develop safe foundations at a reasonable cost; however, the variety of types of soils in the area results in different soil bearing capacities throughout.
The extent of the study area was defined through a latitude and longitude-based coordinate system to allow accurate placement of borehole points that were used in creating the GIS environment. The coordinates provide a method of maintaining spatial accuracy and ensuring proper alignment of geotechnical data to base mapping. A base map of the study area was produced using OpenStreetMap and satellite imagery within QGIS. The base mapping provides valuable information about the road system, the developed environment, and nearby features that assist in visually locating borehole locations and understanding their spatial relationships.

IV. Data Used

The current research has been developed from a geotechnical and spatial data integration perspective in relation to a GIS based methodology. The backbone of all GIS based analysis is data that is accurate, consistent and well-organized. For the purposes of this study, secondary data collected included soil investigations and borehole reports. The two comprehensive sources of primary data for this work were Soil Bearing Capacity values obtained from both field and laboratory studies. Soil Bearing Capacity values represent the load bearing ability of soils at the various study site locations and are generally obtained from borehole logs, Standard Penetration Test (SPT) data, and additional relevant soil testing laboratory data. Within this study, Soil Bearing Capacity values have been created as a representation of the area (temporal) where a specific borehole is located (spatial).
The GIS model has been constructed using the geographic coordinates (latitude and longitude) that have been attached to each borehole location as an aid in correctly plotting the coordinate location of each point supporting the borehole on the GIS model output. The GIS system uses the same reference set of latitudes and longitudes ton maintain ano intact spatial relationship between the various data points (locations) on the GIS model output.
If available, all data pertaining to the type of soils and subsurface conditions will also have been included within the overall database as supporting limb to establish correlations throughout the study area with respect to the variation of Soil Bearing Capacity values. However, the reality of the data collection process will yield gaps in the overall dataset as a result of the lack of soil type or subsurface conditions at risk limit in the database.
All of the secondary data that has been incorporated into this study has consisted of base maps that are relevant to the study.

V. Methodology

The methodology adopted in the present study focuses on the use of GIS tools for estimating Soil Bearing Capacity (SBC) over the entire study area. A systematic step-by-step approach is followed to ensure accurate data handling, analysis, and visualization. The complete methodology is carried out using QGIS, which is an open-source GIS software widely used for spatial data analysis.

A. Collection and Preparation of Data

Step one of the methodology includes gathering SBC information derived from currently accessible soil test data (i.e. boreholes, geotechnical reports, etc.), which it represents at precise geographic points of the soil's ability to support weight (i.e. load). Once all SBC values have been gathered, they should be checked for inaccuracies.

Coordinate data (latitude and longitude) have to be associated with each SBC value to pinpoint its location on the map.
All prepared SBC data will be entered into a spreadsheet for subsequent use in a Geographic Information System (GIS) analysis. Arranging SBC data in a well-organized manner will allow for easy importing and analysis into GIS systems.

B. Import of Data into QGIS

QGIS can import the dataset that has been prepared into a point layer using "Add Delimited Text Layer." Latitude and longitude are used to accurately position the borehole sites on the map. Each borehole site location will be represented by a point with an associated SBC value.
If the coordinate reference system (CRS) is not correctly defined then there will be an error calculating distance and area when conducting spatial analysis and will create incorrect results. Hence it is very important to select the correct CRS to ensure spatial accuracy when conducting spatial analysis.

C. Creation of Base Map

A base map is incorporated into the QGIS project to serve as a geographical reference for the study area. OpenStreetMap or satellite images are normally used as a base map.
The base map is useful in visualizing the position of boreholes relative to roads, buildings, and other surface features.
The base map is also useful in determining the boundaries of the study area and improves the readability of the SBC maps produced during the analysis.

D. Spatial Interpolation of SBC Values

In order to estimate soil-bearing capacity (SBC) using GIS methods it is necessary to use spatial interpolation since boreholes from which SBC values are obtained only exist at discrete locations. In this case we will utilize the inverse distance weighting (IDW) interpolation method. IDW assumes that points closer to an unknown location should have greater influence on the estimated value than points farther from that unknown location; therefore IDW is easy to apply and reliable for basic analysis.
Using IDW will yield a continuous SBC surface over the study area demonstrating the spatial variability in SBC.

E. Classification and Zoning of SBC

The interpolated SBC values are categorized into various classes, including low, medium, and high bearing capacity. This helps in determining regions that have similar strength characteristics of the soil.
The SBC zoning maps are created using QGIS with appropriate classification techniques. The zoning maps offer a clear indication of regions that can be treated with shallow foundations and regions that require special foundation treatment.

F. Generation of SBC Maps and Outputs

The final distribution maps of SBC, contour maps, and zoning maps are produced as output of the GIS analysis. The maps act as decision-support tools for engineers and planners.
The produced maps can be used to interpret the spatial variation of soil bearing capacity and can be used effectively in the preliminary planning and design stage of civil engineering projects.

VI. Results and Discussion

This document examines the distribution of soil strength and foundation capacity of the soils at the site using Geographic Information Systems (GIS) to create SBC contour maps of the site.
The SBC map shows that there is a large difference in the soil's bearing capacity throughout the area. Areas with low SBC could cause significant settlement yields if shallow foundations are used.
Areas with low SBC may require excavation or the installation of deep foundations or soil improvement methods.
The spatial variability of SBC demonstrates that different types of shallow foundations, such as isolated footings and raft foundations, can be used successfully in areas with medium to high SBC.
Developers and engineers will benefit from zoning SBC areas to identify construction options quickly. Understanding the zoning areas will help identify areas needing more detailed investigations to determine the suitability of construction or additional investigation into the soils.7. CONCLUSION AND FUTURE SCOPE

VII. CONCLUSION

The current research focuses on how GIS is used to assess Soil Bearing Capacity (SBC) based on geotechnical information and borehole data. QGIS was utilized as a Spatial Analysis Tool for managing, analyzing, and visualizing SBC information spatially over the entire study site.

The GIS approach allows users to estimate approximate SBC values at locations where direct soil data does not exist. The developed SBC Distribution Maps and Zoning Maps provide useful information about the spatial variability of SBC.

Additionally, this method provides an easy way to reduce the cost and time associated with performing extensive soil investigations at the early stages of civil engineering projects. The results of this research demonstrate that SBC GIS Mapping will provide engineers, planners, and design professionals with a way to use mapping to make more effective decisions regarding their projects.

FUTURE SCOPE

The geographic information systems (GIS) approach utilized in this research project produces useful outputs; however, there is significant potential to improve and expand upon the study conducted to date. With the combination of having more borehole locations, as well as having a greater number of soil testing results, both in the field and the lab, it is possible to produce greater accuracy with regard to estimating soil bearing capacity (SBC). As more data points become available, the ability to provide accurate spatial interpolation results increases.

Additional research will involve using geophysical techniques, including electrical resistivity surveys and seismic methods to improve subsurface characterization. The (GIS) domain represents an opportunity for combining borehole and geophysical data and thus decreasing the uncertainty associated with unknown subsurface conditions. Advanced interpolation methods and machine learning models can be employed to increase both prediction accuracy and reliability of SBC estimation in the future.

The creation of three-dimensional subsurface models using GIS will provide better visualization of soil layers as well as the change in bearing capacity with increasing depth, providing engineers with a tool to understand complex unknown subsurface conditions more effectively. The development of web-based GIS platforms will allow ease of access to, sharing of, and real-time updates regarding geotechnical data for practical use.

The methodology used in this research project can be utilized on a larger scale and over different soil types, thus creating a greater opportunity to develop high-quality, accurate SBC estimates for larger areas.

TABLE II: NOVELTY AND UNIQUENESS OF THE PRESENT STUDY

Sr. No.	Aspect	Previous Studies	Present Study (Our Work)
1	Data Usage	Mostly limited to borehole data only	Integration of borehole data with GIS-based spatial analysis
2	Visualization	2D maps or tabular representation	GIS-based thematic maps and zoning of SBC
3	Spatial Coverage	SBC values at discrete locations	Continuous SBC estimation over entire study area
4	Methodology	Conventional analysis methods	GIS-based interpolation using QGIS
5	Decision Support	Limited support for planning	SBC zoning maps for preliminary foundation planning
6	Practical Application	Academic-focused studies	Application-oriented approach suitable for real projects

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