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Geotechnical Site Investigation for Infrastructure Development Project at Jigmeling Industrial Estate in Sarpang, Bhutan

Karma Tempa[1] and Nimesh Chettri[1]
[1]Civil Engineering and Architecture Department, College of Science and Technology, Royal University of Bhutan, Phuentsholing, (21101) (Chhukha), Bhutan.

(Corresponding author: Karma Tempa)
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ABSTRACT: Geotechnical investigation plays an important role in any infrastructure development projects such as in building construction, road, bridges, geotechnical structures, hydropower projects, development of industries and foundations of transmission towers. The outcome of the investigation is the primary source of information for proper planning, safe and economical design. The investigation can be approached in two ways: Deep sub-surface and shallow depth exploration based on the type of structural plan of the projects. In the current study, geotechnical investigations were carried out at shallow depth through Standard Penetration Test (SPT, field test) and laboratory test. The SPT test was conducted to determine the penetration resistance ('*N*'-value) of the subsoil and further this '*N*'-value is used to compute ultimate bearing capacity of the foundation soil through empirical relations. Using factor of safety as recommended by IS code, safe bearing capacity for foundation design are obtained. The suitability and foundation type can also be decided based on this value. Further, laboratory tests were conducted mainly to ascertain physical properties of the subsoil to understand the soil classification type, its densification, compaction behavior and strength characteristics. These physical parameters are primarily required for design of foundations, retaining structures and site development works and assures safety of the infrastructure and economical benefit in long run leading from decrease in the frequency of repair and maintenance, as in many of the cases, deformation or settlement of subsoil has resulted in functional and structural failures causing deterioration of internal road network, failure of pedestrian and side walk pavement, sinking and cracking of plinth protection area undermining the overall stability of the infrastructure and safety of the set-up.

Keywords: Geotechnical Investigation, Infrastructure, Projects, Industrial Estate, Laboratory Test, Standard Penetration Test, Shallow Depth, bearing capacity, Bhutan.

Abbreviations: DPR, Detail Project Report, MDD, Maximum Dry Density; OMC, Optimum Moisture Content; SPT, Standard Penetration Test; FOS, Factor of Safety; IS, Indian Standard.

I. INTRODUCTION

Bhutan is located in a Himalayan region characterized by different geological settings. Due to high seismicity in the region and due to lack of national seismic code [29]. the height of the buildings is restricted to eight storied [30]. However, due to recent advancement in engineering trends, for any infrastructure projects, Detail Project Report (DPR) needs to be prepared signifying project time frame, planning strategy and cost estimate. Geotechnical investigation becomes a part of DPR under strategy planning to study the technical feasibility and suitability of the area to be developed which is a pre-requisite for construction [10]. Apart from it, geotechnical parameters are very necessary in accurate soil foundation design at the initial phase and improvement of failure mitigation in future [21]. Bearing capacity and settlement requirements are two basic criteria to be satisfied in the analysis and design of shallow foundations. The criterion on bearing capacity ensures that the foundation does not undergo shear failure under loading, while settlement requirement ensures that settlement of the structure is within the tolerance limit of the superstructure [2]. PLT (IS: 1888-1971) and SPT are one of the most practiced field test to ascertain ultimate bearing capacity of the foundation subsoil for shallow foundation, although SPT test is feasible to be conducted for higher depth when boring method of investigation are adopted. Also, thorough geotechnical investigation results in information on potentially problematic soils in the area, precautions to minimize damages, cost sharing and reducing maintenance cost [13]. Based on such importance, in the current study, site is explored through field and laboratory test. SPT test was conducted at 1.5m below the original ground surface in three test pits to determine the penetration resistance of the subsoil and further predict the safe bearing capacity [6] in response to structure loadings [10, 4]. The depth of investigation was based on preliminary investigation where the region is geologically stable [23] with plain topographical features with sandy gravel soils over the entire area and three number of test pits were decided accordingly. Of the many site exploration methods, SPT is one of the conventional methods and can be conducted easily within 1-2 hours' time for a pit based shallow investigation [28]. However, it is an indirect method to obtain bearing capacity. There are many empirical correlations [20, 24, 25, 27] being proposed that can use '*N*' value and compute the ultimate strength of the subsoil. It is usually feasible in sandy and clayey soils having lesser amount of boulders or rocks and does not do well in saturated clayey soils [16]. While the stability of the foundation soil is assessed through field SPT test, the behavior of the soil characteristics is evaluated by conducting soil test in the laboratory such as sieve analysis, direct shear test and compaction test. All test procedures confirm to IS code. And this soil test ensures maximum quality and safety throughout the construction project [6] and achieves serviceability and strength requirements [13]. Unlike methods like deep profiling using resistivity equipment, SPT and PLT becomes convenient for field engineers. Moreover, its uneconomical for infrastructures requiring shallow foundation as the previous method are relatively bear high charges. Hence, current geotechnical investigation through field and laboratory test, data are analyzed, discussed and based on the outcomes, recommendation are furnished for the purpose of planning, decision making and design of the infrastructures.

Department of Geology and Mines (DGM) is one of the core agency responsible for maintaining database on geological characteristics of Bhutan and also on aspects of exploring the issues related to disaster scenario in the country. DGM (2009-2019) has done similar studies in some part of Southern Himalayan belt exploring the soil and rock strata properties. However, for the proposed project in Jigmeling, no such work was been done. Moreover, due to the wide vagaries of geological bed within the smaller region in Bhutan, no alternate correlation was possible. At the scope of current research, methodology adopted best suits the need of the project which provide specific data for infrastructure design. The data obtained as explained in this study explicitly fulfills the objective necessitated.

II. STUDY AREA

The investigation area is located in Jigmeling, Sarpang, 2.5 km north of Indo-Bhutan International boundary. It is 9km and 12km from Gelephu domestic airport and Gelephu main town respectively. The total area of 727acres of land (Fig. 1) is earmarked by Royal Government of Bhutan in 10^{th} five-year plan for establishment of one of a first kind of Industrial park in the country with 144 acres for mineral based, 153 acres for agro-based and 135 acres for forest based including service based industries respectively (Business Bhutan, 2019) internally connected with 21km road network [17].

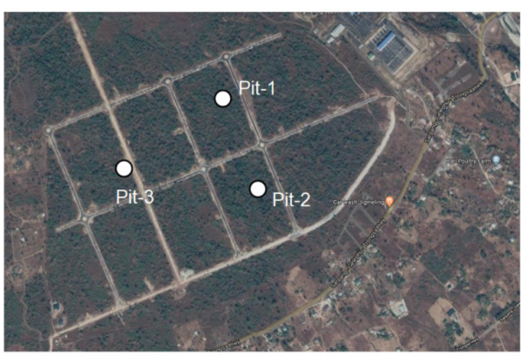

Fig. 1. Jigmeling Industrial park, Sarpang (Google map).

The proposed industrial park is expected to have RCC structures, steel framed structures, load bearing structures, road and pedestrian network, drainage, sanitary and plumbing network aside from electrical works.

III. METHODOLOGY

Classification of soil is a powerful tool to utilize our national soil resource purposefully and scientifically [18, 16]. Field test are one of the most reliable method of investigation in geotechnical engineering but requires proper planning and understanding of the site conditions which decides the types of test to be conducted, number of test pits, settings of the equipment and access to the site. Visit to the site and conducting preliminary investigation involving rapid visual assessment of the area largely aid the overall investigation. This includes visual identification of soils, understanding topographical features, geological conditions and observation of the natural hazards if any. Shallow soil profiling was done through pitting to observe physical nature of the soils. Such field tests look for soil morphological properties in the pits like color, texture, structure, humus content and particle size which are used for soil profiling on the basis of visual observation [9]. At gravel-rich sites, gravel content influences soil compaction behaviour and precompression stress differ strongly. For this reason, it is essential that it be considered when assessing such sites' risk of compaction damage [26].

Typical visual test at site can sometimes be useful where machineries and tools are not available. This test such as visual test, smell test, feeling test, roughness test etc. gives firsthand information on morphological aspects of the soil. However, these test cannot be fully trusted and laboratory test must be done to validate the respective results.

To obtain the detail results of sub soil lithology, one can proceed with the trial pitting which is very common in many geotechnical site characterizations. In the current study, results obtained through filed test and laboratory test are analyzed and interpreted to come up with the suitable recommendation.

While, laboratory test such as sieve analysis, compaction test and direct shear test was conducted to determine basic soil parameters to understand the characteristics of the subsoil. The method adopted in this study is presented in Fig. 2.

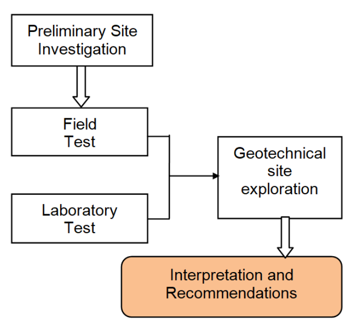

Fig. 2. Methodology adopted for current study.

Soil sample collected from site consists foreign particles which should be segregated and the sample should be oven dried for at least 24 hours. Sampling method and detail test procedures are not covered in this paper but it refers to respective IS codes.

IV. RESULTS AND DISCUSSION

A. Sieve analysis

The basis of Indian Standard Soil Classification System (ISSCS) to classify and identify the soils for engineering purposes is primarily based on the results of sieve analysis which confirms to IS: 2720 (Part 4)-1985, where soils can be broadly classified as coarse grained or fine grained soils and it is the first step. Further, detail examinations of grain size distribution and grading characteristics [23] can substantiate specifics of coarse grained soils including texture and color. Similarly, details of plasticity can be worked out to examine the specifics of fine grained soils using plasticity chart.

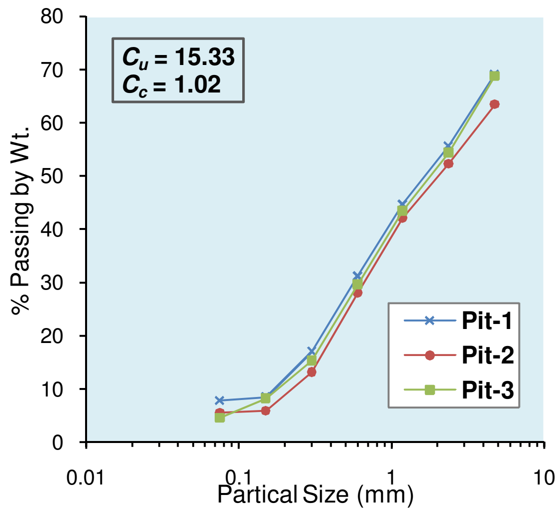

Fig. 3. Sieve analysis results showing grain size distribution.

Fig. 3 shows the grain size distribution of the soil sample from three pits of study location. From each test pit, three samples were tested, analyzed and average value were considered.

The sieve analysis indicates more than 50% fraction of the total soil sample retained over 0.075mm IS sieve representing coarse grained soil in all the test pits. As per the results, the soil is classified as well graded sand with substantial amount of gravel with some fines, non-plastic, *SW*(NP) which is in accordance to IS: 1498-1970. The gradation was based on coefficient of uniformity and coefficient of curvature. The presence of gravel is more than 30%, 55% for sand and less than 8% for silt and clay particles (Table 1).

Table 1: Grain size distribution in percentage.

Soil types	Particle size (mm)	Pit-1	Pit-2	Pit-3
Gravel and boulders	> 4.75	30.86	36.56	31.19
Sand	4.75-0.075	61.26	57.88	64.17
Silt and Clay	<0.075	7.88	5.56	4.64

B. Direct shear test

Since, the soilsare sandy gravel with little silt and clay content, the direct shear test was conducted to determine the shear strength parameters c and ϕ as per IS: 2720 (Part 13) -1987.The test is also called as shear box test, simple to perform and an oldest test [25]. Values of shear stress at failure are plotted against the normal stress and shear parameters are obtained graphically (Fig. 4). The test results have indicated high value of internal angle of friction owing to type of soils present in the area-sandy gravel.

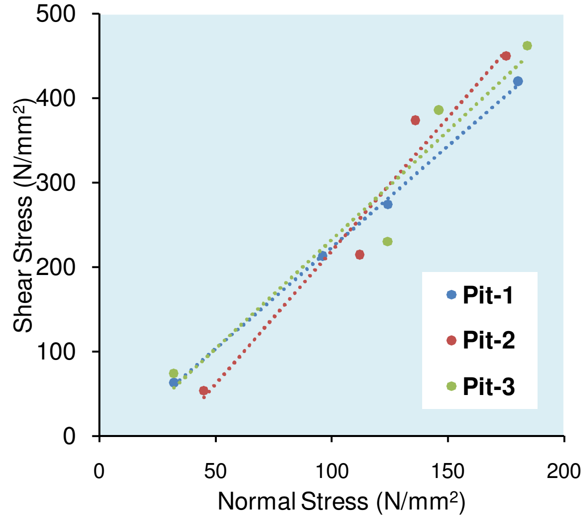

Fig. 4. Direct shear test results.

C. Compaction test

Construction activities usually involves with site development works such as excavation, leveling, placing fills, construction of embankments, landscaping and preparation road bases and in doing so, the in-situ soils are largely disturbed. Hence, at the later stages, compaction for the facility area becomes necessary. Hence, it is important to ascertain the achievable dry bulk density and moisture content for optimum compaction of the soil material in construction [26].

As per Indian Standard, there are two types of compaction test namely standard proctor test (Light) and modified compaction test (Heavy). In the current study, heavy compaction test was carried out owing to heavy traffic within the study area and that light compaction test cannot reproduce the field densities for heavier loadings [15]. The soil samples are subjected to compaction with different water content in layers of five receiving 25 numbers of blows with hammer weight of 4.9kg from 450mm drop height. The densification is measured in terms of dry density given by

$$\gamma_d = \frac{\gamma_t}{1+w} \quad (1)$$

Where, γ_t and γ_t are dry density and bulk unit weight in kN/m^3 and w = water content (%).

Principally, compaction is a method of applying mechanical effort to the disturbed soil layer to density it by rearrangement of the particles and reducing the void ratio. The compaction process helps in regaining the shear strength there by increasing the bearing capacity and reducing the settlement under working loads. A series of soil samples with different water contents were compacted and the curve was plotted between dry density and water content.

The maximum value on y-axis is the maximum dry density (MDD) and the corresponding value on x-axis is optimum moisture content (OMC).

As per the test, MDD and OMC were 1.49 g/cc and 23.33 % respectively. The high value of OMC indicates higher void ratio requiring more water to fill up the voids which happens in coarse grained soils. This can be addressed by incorporating high compaction effort [15] which will lead to increase in maximum dry density at the dry side of the compaction curve requiring less amount of water to be added at the site. Field test shall be conducted to check the densification of the compacted layer as per Bhutan standard [12].

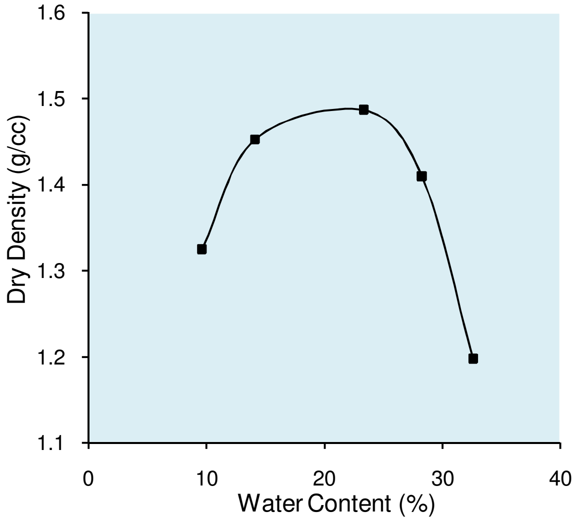

Fig. 5. Relationship between dry density and water content.

D. Standard Penetration Test (SPT)

SPT was conducted confirming to IS: 2131-1981.The test gives penetration resistance *N*-value which is also the bow counts of last 30cm penetration of split spoon sampler driven by hammer weight of 65.0kg from 75cm height through guide pipe assembly. The split spoon sampler is connected by the extension rod called A- drill rod and are useful for deeper exploration. The split spoon sampler is marked with 45cm penetration depth and driven into the soil. The number of blows required to drive each 15cm mark is noted. However, blow count of first 15cm is considered as seating value or seating load. The number of blows required to penetrate last 30cm is called as the '*N*' value.

In order to further utilize the *N*-value, it was corrected for overburden pressure and checked for dilatancy correction to get *N*-corrected "N_{cor}' and corresponding ϕ -value were correlated.

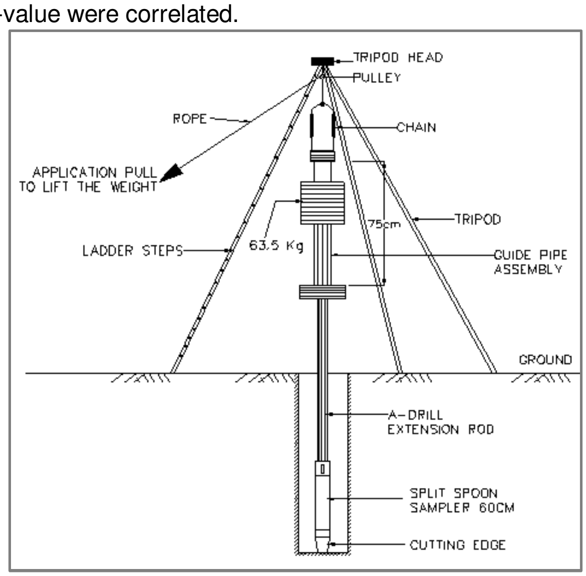

Fig. 6. Schematic diagram for SPT.

In SPT test, shallow the depth (<2.0m) of foundation, smaller the size of the pit is required. For larger depth of the foundation (2-4.0m), bigger the size of the test pit is recommended to comfortably conduct the test.

The summary of the bearing capacities of the various test locations are presented in Fig 8. Based on the corrected 'N_{cor}' value, the angle of internal friction is estimated (Meyerhof, 1956) [17]. Bearing capacity factors are based on ϕ-value proposed by Peck, Hanson and Thornburn1974.

Bearing Capacity. The bearing capacity of the soil is determined based on the SPT test value at Pit-1 and Pit-3 considering the worst case scenario. Based on the corrected '*N*' value, the angle of internal friction is estimated according to Meyerhof, 1956. Bearing capacity factors are based on ϕ -value proposed by Peck, Hanson and Thornburn, 1974.

Fig. 6. Standard penetration test setup

Table 2. Parameters details for three test pits.

Pit No.	Field SPT Value '*N*'	Bulk Unit Weight (kN/m^3)	Depth of foundation, D_f (m)	Overburden Pressure, $\sigma'=\gamma.D_f$ (kN/m^2)
1	14	18.21	1.5	27.32
2	15	18.21	1.5	27.32
3	14	18.23	1.5	27.35

Table 3. Correction to field '*N*' value and corresponding angle of friction.

Correction for Overburden Pressure, $C_N = 0.77\, log_{10} \frac{2000}{\sigma'}$ kN/m^2	Corrected SPT Value 'N_{cor}'	ϕ Meyerhof, 1956
1.44	20	33˚
1.44	20	33˚
1.44	20	33˚

Shear criteria (Terzaghi 1943) [19-20]. For cohesion less soil and square footings, Terzaghi's ultimate bearing capacity equation is given by

$$q_u = \sigma' N_q + 0.4 \gamma_t B N_\gamma \quad (2)$$

Where, $\sigma' = \gamma D_f$ indicates overburden pressure (kN/m^2), N_q and N_γ are bearing capacity factors proposed by Peck, Hanson and Thornburn, 1974 [22] and γ_t and *B* are bulk unit weight of soil (kN/m^3) and width of the footing (m) respectively; Corresponding to ϕ = 33˚ (N_q = 15 and N_γ= 14)

Substituting all the values in Equation 2, the ultimate bearing capacity are computed and applying factor of safety 2-3, the safe bearing capacity (q_s) are obtained as shown in Fig. 8.

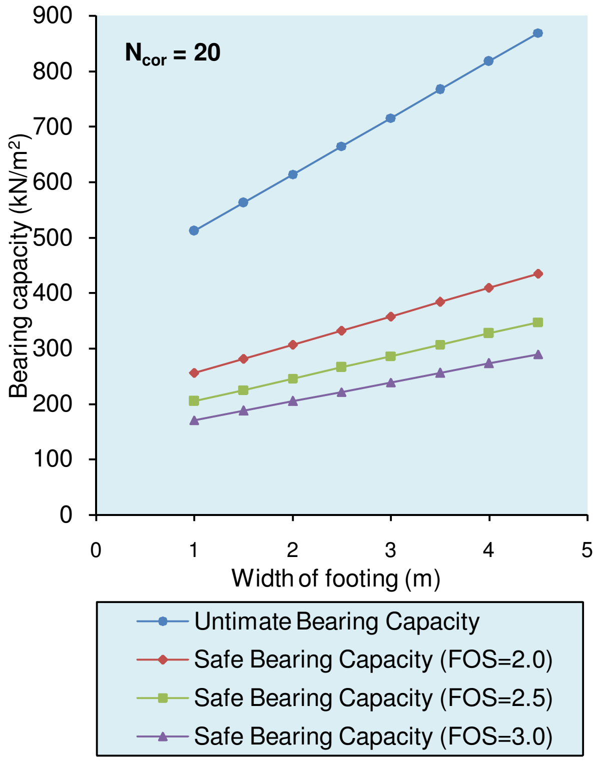

Fig. 8. Variation of ultimate and safe bearing capacity with footing width for different factor of safety.

Settlement criteria (Peck, Hanson and Thornburn 1974). Bearing pressure shall be checked and verified with bearing capacity using Equation 3.

$$q_{a\text{-}net} = 0.44\ C_w \times N_{cor} \times S_a \quad (3)$$

Where,$q_{a\text{-}net}$ represents allowable bearing pressure (kN/m^2), C_w is correction factor for water table position and S_a denotes permissible settlement. IS:1904-1986 recommends maximum settlement (S_a) of 50mm and 75mm for steel and RCC structures, however it is suggested that the value may be taken as a guide and the permissible settlement in each case should be decided as per requirements of the designer. However, it cannot be more than the recommendation. In present study 25mm was considered based on the type of soil.

As per the results in Fig. 8, the ultimate bearing capacity show much higher value. Based on the preliminary site investigation, it was observed that, substantial amount of gravel mixed with sand and silt were present. This can also be understood through field penetration resistance (*N*-value) as shown in Fig. 9.

Depth of foundation. The minimum depth of foundation according to Rankine's theory is given by:

$$h = p/w\ [\ (1-\sin\phi^{\circ})/(1+\sin\phi^{\circ}) \quad (4)$$

Where, h is depth of foundation (m), w = unit weight of soil (kN/m^3), p = safe bearing capacity of soil (kN/m^2) under the footing and ϕ = angle of internal friction.

Note. The safe bearing capacity shall be checked for safe bearing pressure for settlement criteria as per IS: 1904-1986 for required permissible settlement. In most cases, coarse grained soils usually undergo immediate settlement under the working loads and doesn't impose much problem, however, soils with consolidation problem like soft and saturated clayey soil, the settlement criteria may be more critical and safe bearing pressure shall be considered for the design of foundations.This morphological soil is characterized by high spatial variability in terms of their grain size distribution and consistency. This fact also results in a considerable spatial variation of strength and deformation parameters in the subsoil [32].

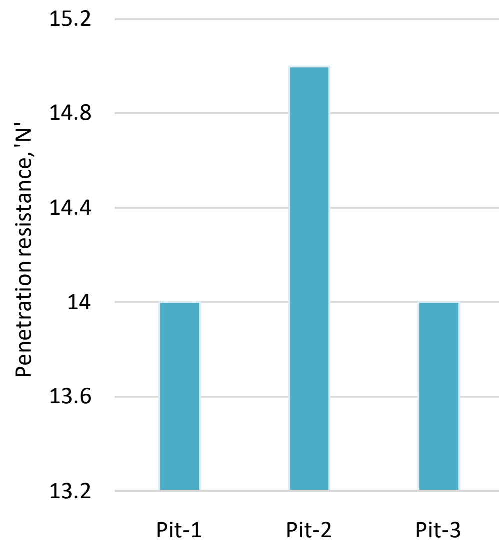

Fig. 9. Penetration resistance in different test pits.

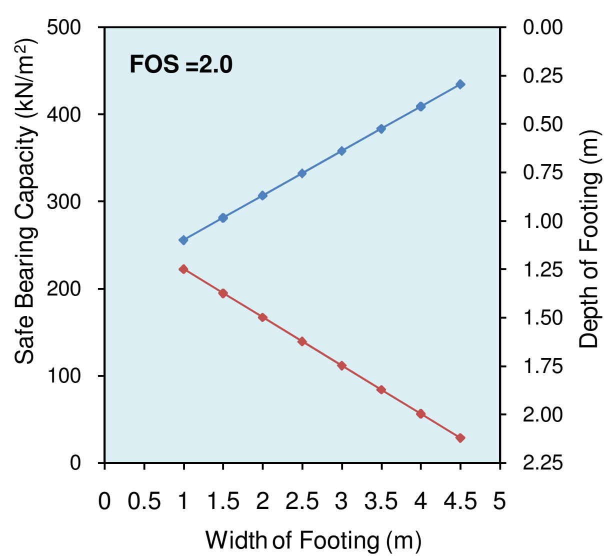

Fig. 10. Variation of depth of footing with safe bearing capacity corresponding to width of footing: FOS=2.0.

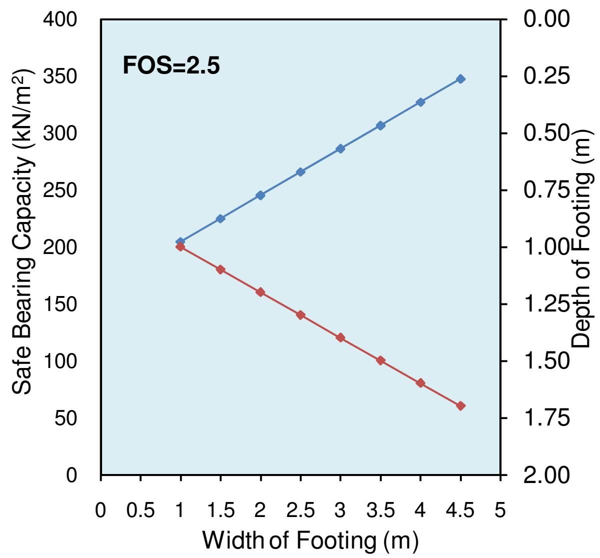

Fig. 11. Variation of depth of footing with safe bearing capacity corresponding to width of footing: FOS=2.5.

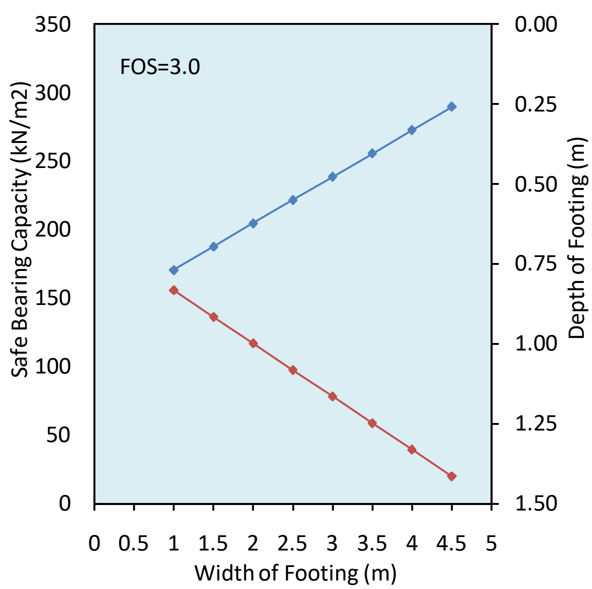

Fig. 12. Variation of depth of footing with safe bearing capacity corresponding to width of footing: FOS=3.0.

V. CONCLUSION

As per the investigation, the soil is classified as well graded sand with substantial amount of gravel with some fines, non-plastic, *SW*(NP): Gravel>30%, Sand>55% and Silt, Clay<8%. The coefficient of uniformity and curvature are 15.33 and 1.02 respectively.
In foundation analysis and design, bearing capacity requirements is one of the two basic criteria to be satisfied. Bearing capacity requirement ensures that foundations do not undergo shear failure under loading [3].In the current study area, the soil is very good for shallow foundation: Isolated (flat, sloped or stepped), combined, trapezoidal or strap footing. Also, the soil is suitable for all types of construction.
The study area contains cohesion less soils (c=0) with higher value of ϕ-values from direst shear test and *N*-value. This is due to presence of gravels and cobbles. Minimum ϕ-value was taken for obtaining safe bearing capacity. The safe bearing capacity ranges between 150 to 250kN/m^2 for a maximum footing width of 4.5m with factor of safety as 3.0. Based on SPT results, the soil type is medium soils which confirms to IS: 1983-2002.
In terms of compaction behavior, the soil of the study area requires greater mechanical effort to achieve MDD and OMC of 1.49 g/cc and 23.33% respectively. The compacted layer shall not have field density < 95% of MDD and +or-2% of OMC. However, OMC can be reduced if mechanical energy is enhanced during the execution.
The minimum depth of footing shall be as per chart shown in Fig. 10, 11 and 12. For factor of safety of 2.0 to 3.0, the minimum and maximum depth of foundation are 0.83m and 2.12m respectively. The assumed depth and depth of exploration of 1.5m is close to the average value of the minimum footing depth which is a valid judgement.

VI. FUTURE SCOPE

The study was based on the set of data from field and laboratory test. The paper had been simplified and detailed the concept of geotechnical site investigation through years of experiences.
The investigation deals specific to the test required for planning and design. This has significantly brought down the overall investigation cost. Hence, this paper may be a good basis for government agencies who have limited technical background in future for similar infrastructure projects. It will also benefit civil engineers at large.

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Conflict of Interest. The authors declares no conflict of interest.

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