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An Extensive Cost Risk Indexing for the Coastal Karnataka Region Based on Soil SBC

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Abstract In India, laterite soil is one of the soil types that is most frequently used for foundation work. Construction of structures uses laterite soil not only for the foundations but also for structures constructed beneath the soil and by incorporating soil as a material for blockwork during the execution phase. It is hence important to carry out the extensive cost risk index of this construction-rich region to estimate the least risky areas and extremely dangerous regions that would yield a beneficial analysis. Firstly 30 study regions have been identified on the coastal Karnataka belt that has lateritic soils. For the soil from different study regions, extensive geotechnical unconfined compressive test procedures were done, followed by implementing risk analysis to get the risk zones. In addition, a structural analysis using the ETABS software is also undertaken to get isolated footing dimensions for these study regions. Earthquake loads, punching, and one-way shear have been considered while designing the footings. Finally, a cost-based risk index is produced considering the present industry labour rates and concreting rates of the region. This risk analysis based on cost and soil-bearing capacity gives a bird-eye view of the risk levels throughout the coastal belt of the Karnataka area. Risk mitigation measures such as ground improvement techniques, consolidation, etc. can now be effectively taken based on the results of the analysis. The results indicated that around 17% of the regions come under extremely risky zones and all regions with respective risk levels were identified. Hence, it can be concluded that for the extremely risk zones, it is better to ignore those land portions or go for ground improvement before construction.

Keywords Lateritic Soil, Risk Analysis, Soil Bearing Capacity, Risk Matrices, Risk Zones

1. Introduction

The behavior of the soil at the site during and after construction has a significant impact on the project's economy and safety. It is considerably essential to assess the site conditions, and soil-related risks for any proposed structure. To understand the strength variations in the study zones, characterizing the zones that pose risks in the construction of buildings is important. Every construction project faces risks that threaten its successful completion as measured by cost, time, and quality. These risks are to be managed and assessed in the first stage of risk management. Risk management intends to make out alleviation strategies to diminish the possibility and happening of an event. The goal of the study is to determine the effect of these inherent laterite soil properties on the foundation cost of residential buildings. The risk model is recorded, which will indicate the risk occupied in the construction in the zonal map. This will assist builders, consultants, and contractors in taking safe measures during construction.

In this study, the impact of the relationship between the size of the footing and the safe bearing capacity of the soil is studied and the risk assessment is conducted and recorded. The impact of the shape and geometry of the footing on the SBC of the soil is concerned with shear failure [1]. The authors in the literature [2] considered different parameters like optimum moisture content, foundation shape, geometry of the foundation, cohesion, maximum dry density of the soil, internal frictional angle, and foundation depth to find the value of soil bearing capacity for comparison. The authors observed that irrespective of all the considerations, if the foundation depth is changed, there is no variation in the property of the soil, but as the foundation's width and breadth increase, there is an increase in soil-bearing capacity [2].

In a planned project, there will be an occurrence of the risk at any time of the event which can delay or halt the completion of it. Therefore, in any project, a risk assessment should be done which will help to know about the risk effect and also its risk probability that can arise. For an event to happen, there are some reasons and results of it. The author in an article [3] states that the cause of the event to happen is called reason and during the project leading, there will be an impact which is called result. So, to know the risk at any event and to overcome it, effective risk analysis methodology has to be adopted, by considering risk guidelines and factors in forming the risk matrix. The risk matrix is developed based on the probability of the risk happening and the risk effect co-related to decide the amount of risk and rank the risk or uncertainty on the project. This risk can be assessed based on the site risk parameters such as the cost involved, schedule, labour cost, properties of soil, etc... To form a risk profile, an analysis has to be done according to the study zones and assessed with low, medium, and high-risk zones [4].

2. Objectives

A complete risk analysis for the coastal Karnataka area by creating a zone map that details the cost risks associated with developing a structure.

3. Methodology

Extensive data is required for such an analysis to be carried out. The first step was the collection of data about the coastal Karnataka region. This gave a database for the geotechnical properties of various soils in the region. Structural analysis was the next approach, for which the ETabs software was used to model a G+4 building and incorporate earthquake loads. ETabs helped extract the dimensions of the isolated footings for thirty regional SBC values. When we go with low-rise buildings, which can be up to 25m tall, the elements are not governed by wind load. They will either be governed by limit gravity (limit loads) or else they will be governed by seismic loads. So, in the severe cases when the building is located in Zone 4 or Zone 5 region, we must go forward with the ductile detailing. Since zone 3 is applicable in all the regions under study, we go forward with the ordinary moment resisting strength.

Provisions mentioned in IS 1893 (Part-1): 2002 (mainly concerning buildings) are used for obtaining the footing dimensions. For Earthquake Zone 3, the factor was 0.164. The importance factor was taken as 5 and the response reduction factor (r) (it depends on the frame used) was taken as 3. Since the structure is an ordinary moment resisting frame, hence r value has to be taken as 3. Earthquake depends upon the period of building. To calculate this period, we use the formula to from a clause in code that uses height from base (h) and the horizontal dimension (b). As Length=breadth here, along both directions period will remain the same.

Next, the acceleration coefficient is needed to be worked out (A_h). To calculate the A_h, factor z value taken as 0.16 and spectral acceleration (based on maximum/fatal possible earthquake) have been derived. The seismic weight of the building is multiplied by the Ah factor to get the base shear. This base shear has to be distributed throughout as lateral loads. The p-delta effect should also be taken care of by doing a separate iterative process. Hence, we get the additional stability of the P-Delta effect.

Manual calculations were done to arrive at the footing dimension. We start with the loads that are acting on the footing; these are unfactored loads. To obtain the factored loads, a pressure diagram is used. These pressure diagrams give the pressure acting on the footing. Using the above pressure acting on the footing the moment will be calculated and verified to check whether it is satisfying the bending moment criteria. Two more criteria have to be met for the footing i.e. one-way shear and the two-way shear. One-way shear will be checked at a distance of d from the edge of the column; this tells us whether the footing can resist the shear or not. In the case of two-way shear, we check at the perimeter from the edge of the column at a distance of d/2.

Present industry rates were collected from firms in the region about footing concreting costs and labor rates for the same activity. For each of the three cases, a different value for service load was calculated using ETABS. Based on specified locations load and SBC values, the area of the footing is determined.

Total costs have been estimated as the sum of labor and concreting costs for the volume of footing generated through ETabs for benchmark cases and the other 30 regional cases. The prevalent cost risk was hence estimated. The Karnataka zone map is prepared to contain cost risk from extremely risky to low-risk areas.

3.1. Benchmark Cost Estimation

As the earth must support the entire structure via the foundation, the key factor affecting cost variation is assessed concerning the foundation. The estimation for building foundations has been generated by combining certain reasonable assumptions and practical dynamics. A summarized gist of the structural analysis is as follows:

ETABS was used to analyze three building configurations with base dimensions of 5m*5m, 7.5m*7.5m, and 10m*10m, each five-storey high. The plan was plotted, and load combinations were added employing IS codes. The structural integrity was determined through analysis, and the base reactions produced were observed. This value represents the ultimate service load, and it was used as the benchmark service load for the three different scenarios studied. The foundation under consideration is an isolated footing with 400 mm*400 mm column size, longitudinal bars ranging from 12mm to 20mm, and M25 concrete. As a reference, an SBC of 250 kN/m^2 at 1m depth is considered.

Furthermore, the cost of concreting M25 per cum is taken to be INR 5200/-, presenting industry scenario data obtained from Qcrete Readymix Pvt. Ltd. (since M20 and M25 are minimum grades). Calculations were carried out in the same manner for the service loads obtained with the gained value of SBC for the 30 areas studied. Concrete is priced at INR 5200/- per cum, based on current practical considerations. In Karnataka, the Labour rate for footing concrete is around INR 35 to INR 40 per (cubic foot) or **1350 to 1500 Rs per cum**. The ETabs structural EQL modelling considering the benchmark SBC of 250 kN/m^2 yielded the benchmark cost values as depicted in the table below.

Table 1. Benchmark cost

Base Dimension (m)	Footing Lxbxh (m)	Footing Volume (m^3)	Total Cost (INR)
5X5	2x2x0.65	2.600	17,420
7.5X7.5	2.4x2.4x0.85	4.896	32,803.20
10X10	2.8x2.8x1	7.840	52,528

For the 5m X 5m dimension:-

$$\boldsymbol{T_a = \frac{0.09h}{\sqrt{d}} = \frac{0.09*15}{\sqrt{5}} = 0.603} \quad (1)$$

$$\boldsymbol{A_h = \frac{\frac{Z}{2}*\frac{S_a}{g}}{\frac{R}{I}} = \frac{\frac{0.16}{2}*2.255}{3} = 0.06} \quad (2)$$

Where, Period
A_h - acceleration coefficient;
h - height from base & d = breadth;
Z - factor, S_a=pectral acceleration.
R- the r factor value (IS 1893-Part 1)

$$Seismic\ Weight = Dead\ Load + 0.25 * Live\ load \quad (3)$$

Footing Area = 2 X 2 m^2
Footing depth = 650mm and Steel along both directions 16@100 c/c
Similarly, for the 7.5m X 7.5m dimension:

$$\text{Spectral acceleration, } \boldsymbol{\frac{S_a}{g}} = 2.50 \quad (4)$$

$\boldsymbol{T_x}$ = 0.846s, where $\boldsymbol{T}$ is time
T_y = 0.493s
A_h = 0.0625
Footing Area = 2.4 X 2.4 m^2
Footing Depth = 850mm and Steel along both directions 16@100 c/c
Similarly, for the 10m X 10m dimension:
T_a = 0.4269
A_h= 0.068
Footing Area = 2.8 X 2.8 m^2
Footing Depth = 1000 mm and Steel along both directions 16@100 c/c

4. Results

From a literature survey on geotechnical properties of laterite soil in coastal Karnataka, the SBC of soils for the 30 regions was obtained.

The values of SBC in kN/m^2 for the 30 study regions as follows, Mundkoor - 477.149, Mulki - 338.344, Aikala - 229.813, Niddodi - 261.212, Bajpe - 163.019, Benjana Padavu - 285.818, Thokkottu - 151.235, Deralakatte - 273.097, Mudipu - 204.981, Bailur - 277.55, Ajekar - 142.52, Muratangady - 321.06, Karkala - 180, Hriyadka - 244.55, Kolalagiri - 310.37, Udupi - 413, Katapady - 308, Kapu - 144.929, Shirva - 97.544, Uchila - 257.296, Jantra - 108.53, Hejmady - 209.846, Haradi - 123.66, Kumbashi - 109.118, Hemmadi - 292.911, Neralakatte - 279.56, Vandse - 246.69, Kota - 229.813, Sasthana - 108.53, Kandluru - 209.85 respectively [5] [6] [7] [8].

4.1. ETABS Analysis for Regional Cost Values

Then, ETabs structural EQL modelling considering the actual regional SBC values is done for the 30 regions under study. Derived footing dimensions for a single case of base dimensions 5X5 m^2, only for 5 areas namely Mulki, Aikala, Bajpe, Vandse, and Uchila are shown in Table 2.

Table 2. Footing dimensions [7]

Place	Base Dimension (m)	Footing length (m)	Footing breadth (m)	Footing height (m)
Mulki	5X5	1.70	1.70	0.65
Aikala	5X5	1.95	1.95	0.65
Bajpe	5X5	2.45	2.45	0.65
Vandse	5X5	1.90	1.90	0.65
Uchila	5X5	1.90	1.90	0.65

Followed by the yielded regional cost values for the areas considered in Table 2. A sample of regional cost values (for building base 5 X 5 m^2) is depicted in Table 3 below.

Table 3. Total cost for study regions [8]

Place	Base Dimension (m)	SBC (kN/m^2)	Footing Volume (m^3)	Total Cost (INR)
Mulki	5X5	338	1.87	12585
Aikala	5X5	229.81	2.47	16549
Bajpe	5X5	163.02	3.90	26130
Vandse	5X5	246.69	2.37	15847
Uchila	5X5	257.29	2.31	15449

Similarly, the analysis is carried out for all the remaining 25 regions for all three cases of building base. The total cost is derived by multiplying the footing volume by INR 6700. The value is obtained by arithmetic summation of the labor rate and RMC costs i.e. INR 1500 and INR 5200 respectively.

4.2. Preparation of Risk Model & Zonal Risk Areas

After reviewing the literature on geotechnical graphs and results, all of the curves demonstrate the gravely character of the laterite soil sample. It mimics the top region of an S-curve. A risk matrix is utilized to rank the uncertainties, allowing us to create a hierarchy of risk zones from most expected to least expected. The main aspect for finding the risk is done based on the safe bearing capacity values obtained from thirty selected places obtained from UCC. A risk matrix is a qualitative risk assessment tool that rates the risk according to the two most adopted criteria, namely, consequence and likelihood or other similar expressions like severity and probability, etc. [9, 10]. To estimate the severity of a risk by employing a risk matrix, decision-makers need to estimate the consequence and likelihood of the risk occurring only subjectively and the risk matrix outputs the risk rating, denoted by a particular colour, like red, orange, green, and so on. Due to its simplicity, the risk matrix has been widely used in many fields such as agricultural pollution management [11], and safety management systems [12].

The risk matrix is formed using the principle of the Likert scale, which is a tool used to comprehend the level of acceptability, level of probability, level of priority, and so on. Likert scales are commonly used either as a seven-point scale or a five-point scale. For the sake of simplicity, a five-point Likert scale in which the risk is categorized as low, high, very high, very low, and normal is chosen. With the help of the formed matrix, cost risk concerning safe bearing capacity in all the study places is estimated. The key factors used for creating the risk matrix are three - They are the M (mean value of SBC) & SD (Standard Deviation) and risk probability. The mean and standard deviations are calculated and tabulated with certain notations used for cost risk and SBC risk which start from one (very low) to five (very high) and are based on the scale. The mean of 30 SBC values is 233.33 kN/m^2 and the standard deviation is 91.94 kN/m^2. The risk is represented at an intensity level from green to red, with green representing minimal risk and red signifying severe risk as shown in Table 4. The selection of these colors to represent risks is entirely dependent on the self. The likelihood of risk is computed by multiplying the SBC risk by the cost risk, and the peak of risk is thus obtained.

Table 4. Assignment of risk [11, 12]

Formula	Value	Assignment	SBC Risk
M+2SD	417.21	very low	1
M+SD	325.27	low	2
M	233.33	normal	3
M-SD	141.39	high	4
M-2SD	49.45	very high	5

4.2.1. Potential Cost Risk Estimation

The next step in the process is an estimation of the cost risk values for all the thirty regional areas. The inherent cost risk is calculated concerning the benchmark costs calculated initially for the 5X5 m^2, 7.5X7.5 m^2, and 10X10 m^2 base dimensions of the structure. The formula used to calculate the potential cost risk is given below:

$$Potential\ Cost\ Risk = BM\ Value - Reg\ Value \quad (5)$$

$BM\ Value$ - benchmark cost value
$Reg\ Value$ - regional cost values
Now, for a 5X5 m^2 base structure;
$Potential\ Cost\ Risk$ = INR 17420 - $Reg\ Value$
For a 7.5X7.5 m^2 base,
$Potential\ Cost\ Risk$ = INR 32803.20 - $Reg\ Value$
For a 10X10 m^2 base,
$Potential\ Cost\ Risk$ = INR 52528 - $Reg\ Value$

Three possibilities can be examined from this analysis as to no inherent cost risk if the risk values fall below/equal to zero. Another possibility is the case of cost risk being manifested and it will be shown with a negative sign as the regional cost value will go higher than benchmark values. This can later be categorized based on the severity of the inherent cost risk. The obtained potential cost risk values for some of the regions namely Bajpe, Thokottu, Bailur, Ajekar, Karkala, Shirva, Jantra, Kapu, and Kumbashi are displayed in Table 5.

Table 5. Potential Cost Risk

Place	Base Dimension (m)	Total Cost (INR)	Cost Risk (INR)	Cost Difference (%)	Risk
Bajpe	5X5	26130	-8710	-50	very high
	7.5X7.5	44622	-11818	-36.03	very high
	10X10	75174	-22646	-43.11	very high
Thokottu	5X5	29413	-11993	-68.85	very high
	7.5X7.5	58290	-25486.1	-77.70	very high
	10X10	94202	-41674	-79	very high
Bailur	5X5	16482	+930	5.38	low
	7.5X7.5	36582	-3778	-11.52	low
	10X10	48039	+4489	8.55	low
Ajekar	5X5	20502	-3082	-11.32	low
	7.5X7.5	36515	3711.8	-13.14	low
	10X10	59429	-6901	-9.62	low
Karkala	5X5	19095	-1675	-3.55	very low
	7.5X7.5	33969	-1165.8	-5.61	low
	10X10	55476	-2948	-7.69	low
Shirva	5X5	21038	-3618	-20.77	high
	7.5X7.5	37453	-4649	-16.96	medium
	10X10	61439	-8911	-17.31	high
Jantra	5X5	20435	-3015	-17.31	high
	7.5X7.5	36381	3577.8	-10.91	medium
	10X10	59161	-6633	-12.63	medium
Kapu	5X5	18760	-1340	-7.69	low
	7.5X7.5	32830	-26.8	-0.08	very low
	10X10	54337	-1809	-3.44	very low
Kumbashi	5X5	20502	-3082	-17.69	high
	7.5X7.5	36381	3577.5	-10.90	medium
	10X10	59161	-6633	-12.63	medium

4.2.2. Assessment of Estimated Cost Risks

As it is clear from Table 5, any upward difference in cost from the benchmark is well-demarcated with a negative sign preceding it. Now arises the need to assess these inherent cost risks and classify them to make further risk management possible.

4.3. Estimating Risk Matrix Value

$$SBC\ \ Risk * Cost\ \ Risk = Risk\ \ matrix\ \ value \qquad (6)$$

As mentioned earlier, the product of the risk is associated with the cost and SBC delivers the risk matrix value as shown in Table 7 and Table 8.

The following scale is used to index the risk in Table 6:

Table 6. Scale to index the risk

Assessment	Risk Ranges
very low	1 - 2
low	3
medium	4 - 9
high	10 - 14
very high	15 - 19
extreme	20 - 25

Table 7. Assignment of risk from extreme to very low

		Cost Risk				
		1	2	3	4	5
SBC	5	medium 5	high 10	very high 15	extreme 20	extreme 25
	4	medium 4	medium 8	high 12	very high 16	extreme 20
	3	low 3	medium 6	medium 9	high 12	very high 15
	2	very low 2	medium 4	medium 6	medium 8	high 10
	1	very low 1	very low 2	low 3	medium 4	medium 5

Now, since the cost part of risk has been analyzed and assessed, we move forward with total risk assessment considering both cost and SBC risks. This will give the comprehensive risk in the region that will help us map the risk management approach.

Table 8. Risk Levels of Study Regions

Place	SBC Risk	Cost Risk	Risk matrix value	Risk Level
Thokottu	4	5	20	extreme
Benjana Padavu	3	1	3	low
Derlakate	3	1	3	low
Mudipu	4	1	4	medium
Bajpe	4	5	20	extreme
Niddodi	3	1	3	low
Mulki	2	1	2	very low
Aikala	3	1	3	low
Mundkur	1	1	1	very low
Hejmady	3	1	3	low
Jantra	5	4	20	extreme
Shirva	5	4	20	extreme
Ucchila	3	1	3	low
Kapu	4	2	8	medium
Katpadi	3	1	3	low
Udupi	2	1	2	very low
Kolalagiri	3	1	3	low
Haradi	5	3	15	very high
Sastana	5	1	5	medium
Kota	4	1	4	medium
Kumbashi	5	4	20	extreme
Neralakate	3	1	3	low
Hemmadi	3	1	3	low
Vandse	3	1	3	low
Kandluru	4	1	4	medium
Bailur	3	2	6	medium
Ajekar	4	2	8	medium
Muratangadi	2	1	2	very low
Karkala	4	2	8	medium
Hriyadka	3	1	3	low

From the above study conducted, the following points can be observed and are discussed below.

5. Discussion

The key observations are as such;

According to the risk matrix created, out of the thirty sample regions chosen, five locations—Thokottu, Jantra, Bajpe, Kumbashi, and Shirva—were discovered to be in extreme risk areas. Haradi happens to be the only region at extremely high risk. An interesting phenomenon is observed with Haradi, as the base size of the structure increases the risk reduces and eventually grabs a positive value that signifies cost saving.

Mulki, Mundkoor, and Hemmadi having high values of SBC give the least SBC risk as well as the least cost risk. As per the calculations made the cost risk was found to be higher in Thokottu and Kumbashi with a considerable increase in the cost of construction of the foundation.

6. Conclusions

Around 17% of the regions in coastal Karnataka come under extremely risky zones that cause a negative ripple effect on the cost of foundations and building costs at large. Haradi being the singular high-risk zone contributes to 3.33% of the coastal region. Birds' eye view gives that 20% of regions are going to incur larger costs of construction. For analysis of high-rise structures, structural analysis has to be done considering the wind load’s role on the structure. Although for simplicity the results published in this for low rise can be generalized up to a certain extent for a high rise as earthquake loads according to the earthquake zone have been considered. The future scope of this analysis would include a detailed study of the water table fluctuations that can be done to increase the efficiency of the cost risk model. Other regions of Karnataka can be added to the analysis to get a more exhaustive data set.

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