

Reliability-Based Design of Pad Foundation on Soft Clay in the Coastal Niger Delta Region

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Abstract: - This study examines the reliability-based design of pad foundations on soft clay at a site in the coastal Niger Delta. A quantitative case-study approach was used, combining field sampling, laboratory testing, bearing-capacity analysis, settlement prediction, and probabilistic modelling to assess foundation performance under uncertainty. The soil profile was dominated by soft, highly plastic clay with shallow groundwater and low shear resistance. Ultimate bearing capacity increased modestly with footing aspect ratio, from 134.20 kPa at B/L = 0.50 to 148.33 kPa at B/L = 1.00. Reliability analysis showed that settlement, rather than bearing capacity, governed design at the site. Settlement remained critical, with the 50 mm Eurocode limit and target $\beta = 1.5$ satisfied only at FS $\approx$ 4.5–5.0. The results suggest that allowable foundation pressures in the range of about 30–42 kN/m² are required to satisfy the adopted reliability and serviceability criteria for the conditions studied. The findings are site-specific and should be interpreted as a case-based reliability assessment rather than a general regional rule.

Keywords: Bearing Capacity, Monte Carlo simulation, reliability index, settlement, Shallow Foundation, Soft Clay

1.0 INTRODUCTION

Soft clay deposits in the coastal Niger Delta create major challenges for shallow foundation design because they are usually saturated, highly compressible, and weak in undrained shear strength. Abam (2016) identified mangrove swamp soils as the weakest geomorphic unit in the region, reporting undrained shear strengths generally below 20 kPa and consolidation settlements of about 180 mm under moderate loading. Similarly, Nwankwoala et al. (2015), Warmate (2018), and Ehibor et al. (2019) reported high moisture content, low shear strength, high compressibility, and poor bearing capacity in soft clay and silty clay deposits across different parts of the Niger Delta. Taken together, these studies show that shallow foundations on untreated deltaic soils are highly vulnerable to excessive settlement and serviceability failure.

Although these studies agree on the poor engineering quality of Niger Delta soft soils, they differ in their assessment of foundation risk and remedial performance. Abam et al. (2023) showed that significant settlement can still occur in reclaimed mangrove swamps after hydraulic sand filling, although acceptable long-term behaviour may be achieved when consolidation and drainage are properly considered. In contrast, Beresibo and Baribeop (2019) emphasised the limitations of shallow foundations in untreated soft deposits and stressed the need for careful settlement assessment prior to construction. While both studies identify settlement as the key design issue, one focuses on reclaimed-ground performance and the other on natural-soil conditions.

A further distinction lies in scale and scope. Studies such as Abam (2016) provide a broad regional characterisation of the Niger Delta geomorphic units and their engineering behaviour. In contrast, Nwankwoala and Warmate (2014), Ehibor et al. (2019), and Dickenson et al. (2021) adopt site-specific investigations and show that soil properties can vary significantly over short distances. These local studies indicate that foundation

performance may change with stratigraphy, groundwater conditions, organic content, and depositional history, meaning that regional characterisation alone is insufficient for detailed foundation design.

Methodologically, most of the reviewed studies rely on conventional geotechnical investigations, including borehole logging, laboratory testing, CPT, and settlement analysis, and therefore present largely deterministic conclusions based on average or characteristic soil parameters. By contrast, Al-Dawoodi et al. (2022) used numerical modelling with advanced soft-soil constitutive models to simulate the behaviour of shallow foundations. Although this provides a more refined representation of soil–structure interaction, it still depends on assumed input parameters and does not explicitly quantify uncertainty in soil variability.

Overall, the literature shows a clear progression from regional geological characterisation to site-specific geotechnical assessment and finally to foundation performance evaluation. However, nearly all studies still assess safety using deterministic factors, without explicitly quantifying the probability of failure due to variability in undrained shear strength, unit weight, groundwater level, compressibility, or loading conditions. This leaves a gap between understanding soil behaviour and reliably predicting foundation performance.

Existing studies therefore confirm that soft silty clay deposits in the Niger Delta are highly variable and settlement-prone, but they do not show how this variability affects the probability of bearing capacity failure or excessive settlement. This study addresses that gap by integrating uncertainty and probability into pad foundation design, moving beyond deterministic safety factors to a more realistic reliability-based assessment under Niger Delta ground conditions.

2.0 METHODOLOGY

An explanatory quantitative design was adopted for a case study in Bolou Ndoro, Burutu Local Government Area, Delta State. Three hand-auger boreholes were drilled to a depth of 6 m, and samples were collected at 1m intervals and at lithologic changes. Laboratory testing in accordance with BS 1377 included grain-size analysis, Atterberg limits, unconsolidated undrained triaxial testing, and one-dimensional consolidation testing. These tests provided the soil parameters used in the bearing-capacity, settlement, and reliability analyses.

Foundation behaviour was then modelled analytically to estimate bearing capacity using the reduced Meyerhof's Equation given as Equation 1.

$$q_u = cN_c s_c + qN_q s_q + 0.5\gamma B N_\gamma s_\gamma \quad (1)$$

where s_c , s_q and s_γ are the shape factors, given as

$$s_c = 1 + \left(\frac{B}{L}\right) \left(\frac{N_q}{N_c}\right) \quad s_q = 1 + \left(\frac{B}{L}\right) \tan \phi \quad s_\gamma = 1 - 0.4 \left(\frac{B}{L}\right), \text{ and}$$

$$N_q = \frac{1 + \sin \phi}{1 - \sin \phi} \exp(\pi \tan \phi); \quad N_c = \frac{N_q - 1}{\tan \phi}; \quad N_\gamma = (N_q - 1) \tan(1.4\phi) \text{ are the bearing capacity factors.}$$

For the settlement analysis, the Gazetas-type elastic solution for a shallow footing on a homogeneous half-space (Gazetas *et al.* (1985)) was adopted for the immediate settlement calculations, as given in Equation 2.

$$S_i = \frac{Q_{ext}}{E_s L} (1 - \nu_s^2) \mu_s \mu_{emb} \mu_{wall} \quad (2)$$

Where μ_s , μ_{emb} and μ_{wall} are factors accounting for the shape of the footing, depth of the footing and effect of wall friction, respectively.

With a footing width B of 1m and a depth of footing D_f of 1.2m below the ground level,

$$\mu_s = 0.45(B/L)^{-0.38}, \quad \mu_{emb} = 1 - 0.048(1 + B/L), \quad \mu_{wall} = 1 \text{ and } Q_{ext} = q_{all} \times BL.$$

The consolidated settlement analysis was carried out assuming that both m_v and σ' are constant across the full height H of the layer, we can integrate for the whole thickness of the layer to get the total settlement of the ground surface, given as Equation 3

$$S = m_v \Delta \sigma' H \quad (3)$$

Where;

m_v is the coefficient of volume compressibility

q_{all} is the allowable foundation pressure

The primary consolidation settlement S_c in a single compressible layer, given by Equation 3, was expressed in terms of the allowable bearing capacity and the foundation width B , yielding Equation 4.

$$S_c = m_v \times 0.55 q_{all} \times 1.5B \quad (4)$$

The reliability analysis used the First-Order Reliability Method, Monte Carlo simulation, and response surface methodology (Baecher & Christian, 2003). The response surface model relating the input variables to the output variable is given by Equation 5.

$$y = f(X_1, X_2, X_3, X_4, \dots, X_N) + e \quad (5)$$

Where f is some unknown function of x

Let Equation 5 be represented by a linear polynomial equation given by Equation 6.

$$y = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 \quad (6)$$

The fitted bearing capacity model for the selected study location was tested for adequacy using the coefficients of multiple determinations (R^2) and the adjusted R^2 , with the aid of the statistical tool Minitab 17.0.

In the first-order reliability method adopted, the performance function corresponding to the limit state of interest is the random difference between the structural strength, $R(x)$ and the load effect, $S(x)$ (Lin & Yuan, 2023). For a nonlinear limit state, the performance function is given by Equation 7.

$$g(X) = g(x_1, x_2, x_3, \dots, x_n) = R(x) - S(x) \quad (7)$$

The reduced form of n - dimensional random variables X_i is given by Equation 8.

$$Z = \frac{x_i - \mu_{xi}}{\sigma_{xi}}, \quad (i = 1, 2, \dots, n) \quad (8)$$

Using Equation (8), the limit state equation for n transformed variates is given by Equation 9

$$g(\sigma_{x1} * Z_1 + \mu_{x1}, \sigma_{x2} * Z_2 + \mu_{x2}, \sigma_{x3} * Z_3 + \mu_{x3}, \dots, \sigma_{xn} * Z_n + \mu_{xn}) = 0 \quad (9)$$

Where μ and σ represent the mean and standard deviation of the basic variables, respectively.

The solution of Equation (9) represents the design points on the failure surface, and it is given by Equation (10)

$$Z^* = (Z_1^*, Z_2^*, Z_3^*, \dots, Z_n^*) \quad (10)$$

The structural reliability index is defined as the minimum Euclidean distance from the origin to the design point. This minimum distance is given by Equation (11)

$$\beta = \sqrt{(Z_1^2 + Z_2^2 + \dots + Z_n^2)} \quad (11)$$

The position of the design point on the failure surface is not known. Consequently, an iteration technique is required to locate this point.

3 RESULTS AND DISCUSSION

3.1 Laboratory Test Results

Results from the geotechnical investigation showed that the subsurface soil profile consists predominantly of soft grey silty clay with a shallow groundwater table varying from the ground surface to about 0.3 m below ground level. The laboratory test results are presented in Table 1.

Table .1: Laboratory Test Results / BSC system

BH No	Depth of Sample (m)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Unit Weight γ (kN/m ³)	Angle of friction ϕ (degrees)	Undrained Cohesion 'c _u ' (kN/m ²)	BSCS
1	0.00 - 6.00	159.05	35.71	123.33	19.10	1	23	CH
2	0.00 - 6.00	121.02	36.59	84.43	21.00	2	30	CH
3	0.00 - 6.00	119.37	36.23	83.13	20.50	1	23	CH

3.2 Regression Model Development

The response surface model was developed using the statistical parameters in Tables 2 and 3, including the mean, standard deviation, and random variables derived from the geotechnical data in Table 1. A 2ⁿ factorial design was used to fit regression equations for the three input variables: soil cohesion (c_u), angle of internal friction (ϕ), and unit weight (γ). The maximum and minimum values of these design variables are shown in Table 3. Regression analysis was performed using Minitab statistical software, and the resulting regression models are presented in Equations 12, 13, and 14 for B/L ratios of 0.50, 0.75, and 1.00, respectively.

Table 2: Statistics of the Random Variables

Variables	Mean	Standard Deviation	Coefficient of Variation	Type of Probability Distribution
c _u (KN/m ²)	25.53	3.50	0.138	Normal
ϕ (°)	1.33	0.50	0.375	Normal
γ (KN / m ³)	20.20	0.85	0.042	Normal

Table 3: Maximum and Minimum Values of the Design Variables

Variables	Lower value	Higher value
ϕ (°)	0.508	2.153
c _u (KN/m ²)	19.573	31.088
γ (KN / m ³)	18.802	21.598

The regression model corresponding to B/L = 0.50 is given by Equation 12.

$$q_u = -56.9 + 55.42\phi + 4.357c_u + 0.74\gamma \quad (12)$$

The regression model corresponding to B/L = 0.75 is given by Equation 13.

$$q_u = -58.1 + 56.51\phi + 4.635c_u + 0.75\gamma \quad (13)$$

The regression model corresponding to B/L = 1.0 is given by Equation 14.

$$q_u = -59.1 + 57.51\phi + 4.909c_u + 0.75\gamma \quad (14)$$

Regression models in Equations 12-14, developed to predict ultimate bearing capacity, showed strong predictive performance, with coefficients of determination ranging from 96.79% to 96.97%. The calculated average ultimate bearing capacities were approximately 134.20 kPa for B/L = 0.50, 141.43 kPa for B/L = 0.75, and 148.33 kPa for B/L = 1.0, indicating that increasing the footing aspect ratio slightly improves the load-carrying capacity of the foundation. The combined statistical and strength parameters indicate that the soil is a soft

cohesive clay deposit characterized by low frictional resistance, moderate undrained shear strength, and relatively low-density variability. The high variability in friction angle and moderate variability in cohesion suggest that shear strength behaviour is uncertain and should be evaluated using reliability-based design methods.

3.3 Reliability-Based Design for the Bearing Capacity Criterion

The bearing capacity performance functions were developed from the regression models presented as Equations 12, 13, and 14 for B/L ratios of 0.50, 0.75, and 1.00, respectively. The resulting performance functions are presented as Equations 15, 16, and 17. Reliability-based design was then carried out using these performance functions to determine the reliability index (β), while MATLAB programs were used to evaluate the safety levels of applied foundation pressures under different factors of safety. The average ultimate bearing capacities for B/L ratios of 0.50, 0.75, and 1.00 were 134.20 kPa, 141.43 kPa, and 148.33 kPa, respectively. The results obtained using the First-Order Reliability Method (FORM), together with validation by Monte Carlo Simulation (MCS), are presented in Tables 4, 5, and 6, respectively.

The Bearing Capacity Criterion (B/L = 0.5) is given by Equation 15.

$$G = -56.9 + 55.42\phi + 4.357c_u + 0.74\gamma - q \quad (15)$$

The Bearing Capacity Criterion (B/L = 0.75) is given by Equation 16.

$$G = -58.1 + 56.51\phi + 4.635c_u + 0.75\gamma - q \quad (16)$$

The Bearing Capacity Criterion (B/L = 1.0) is given by Equation 17.

$$G = -59.1 + 57.51\phi + 4.909c_u + 0.75\gamma - q \quad (17)$$

For foundation design, bearing capacity is treated as an ultimate limit state (ULS) problem. In the Eurocode basis of design, the recommended target reliability index for the majority of conventional civil and building engineering structures over a 50-year reference period is $\beta = 3.5$ (European Commission, 2024).

Table 4: Variation of Implied Safety Index with Applied Load for B/L = 0.50

FS	B/L = 0.50 $q_u = 134.20 \text{ KPa}$			Target $\beta = 3.5$
	Q_{uall}	Beta (FORM)	Beta (MCS)	Performance Level
2.0	67.10	2.399	2.4213	Unsatisfactory
2.5	53.68	2.8242	2.8946	Unsatisfactory
3.0	44.73	3.1072	2.9982	Below target and underperforms
3.5	38.34	3.309	3.2986	Below target and underperforms
4.0	33.55	3.4608	3.5123	Meets Marginal Target
4.5	29.82	3.5787	3.6112	Meets Target
5.0	26.84	3.6729	3.7008	Meets Target

Table 5: Variation of Implied Safety Index with Applied Load for B/L = 0.75

FS	B/L = 0.75 $q_u = 141.43 \text{ KPa}$			Target $\beta = 3.5$
	Q_{uall}	Beta (FORM)	Beta (MCS)	Performance Level
2.0	70.72	2.5402	2.6032	Unsatisfactory
2.5	56.57	2.8843	2.8112	Above average
3.0	47.14	3.1737	3.2005	Below target and underperforms
3.5	40.41	3.3803	3.4024	Below target and underperforms
4.0	35.36	3.5354	3.5227	Meets Marginal Target
4.5	31.43	3.6560	3.7297	Meets Target
5.0	28.29	3.7525	3.8342	Meets Target

Table 6: Variation of Implied Safety Index with Applied Load for B/L = 1.0

B/L = 1.0 $q_u = 148.33 \text{ KPa}$				Target $\beta = 3.5$
FS	Q_{uall}	Beta (FORM)	Beta (MCS)	Performance Level
2.0	74.17	2.4985	2.488	Unsatisfactory
2.5	59.33	2.9413	3.004	Below target and underperforms
3.0	49.44	3.2365	3.321	Below target and underperforms
3.5	42.38	3.4473	3.504	Meets Marginal Target
4.0	37.08	3.6055	3.712	Meets Target
4.5	32.96	3.7285	3.8062	Meets Target
5.0	29.67	3.8268	3.8579	Greater than Target Beta but not economical

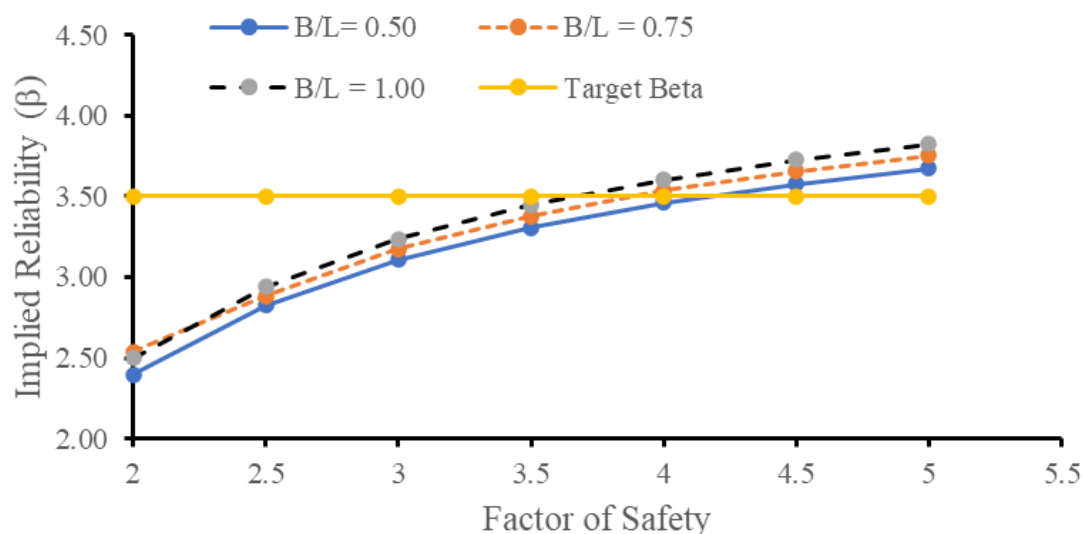


Figure 1 Graph of Bearing Capacity Reliability Index (β) versus Factor of Safety

From Tables 4 to 6 and in Figure 1, it can be deduced that the reliability index (β) increased in tandem with the factor of safety (FS) across all footing aspect ratios, indicating that higher safety factors reduce the probability of bearing-capacity failure. For the rectangular footing with B/L = 0.50, β increased from 2.399 at FS = 2.0 to 3.673 at FS = 5.0. Similar increases were observed for B/L = 0.75 and B/L = 1.00, where β reached 3.753 and 3.827, respectively. The close agreement between the First-Order Reliability Method (FORM) and Monte Carlo Simulation (MCS) results confirms the robustness and consistency of the adopted reliability model.

The results further indicate that footing geometry significantly influences foundation reliability. Reliability indices increased with increasing footing aspect ratio, showing that square footings mobilize soil resistance more efficiently and consequently achieve higher levels of safety than rectangular footings. Comparison with the target reliability index of $\beta = 3.5$ revealed that safety factors below 4.0 were generally insufficient to satisfy the required reliability level. For footings with B/L = 0.50 and B/L = 0.75, the target reliability was attained only at approximately FS = 4.0, whereas the square footing (B/L = 1.00) achieved the target at about FS = 3.5. These findings suggest that conventional deterministic safety factors may not always provide the desired level of reliability. Sensitivity analysis identified the soil friction angle as the most influential parameter governing bearing-capacity reliability, highlighting the importance of accurate determination of shear-strength characteristics during site investigation and design.

Overall, the study demonstrates that both increasing the factor of safety and optimizing footing geometry enhance foundation reliability. However, the results also show that reliance on deterministic safety factors alone

may lead to either underestimation or overestimation of risk. Consequently, reliability-based design, supported by improved geotechnical characterization, offers a more rational and economically efficient framework for foundation design while ensuring compliance with target reliability requirements (European Commission, 2024).

3.4 Reliability-based Design based on Settlement Criterion.

USACE gives the common correlation $E_s = K_c c_u$ for clay, and $K_c \approx 300$ for a normally consolidated high-plasticity conservative case, with $c_u = 25.53$ kPa. Using undrained Poisson's ratio $\nu_u = 0.5$ for undrained immediate settlement presented by Strahler and Stuedlein (2013)

Equation 2 is reduced to Equation 18.

$$S_i = 0.025q_{all}(0.45(B/L)^{-0.38})(1 - 0.048[1 + B/L])c_u^{-1} \quad (18)$$

SHANSEP method, adopted by some researchers and in some standards (Allen (2005). CEN (2004), Doherty et al. (2018), Doherty et al (2018), Vivekananda & Nagaraj. (2025)), was applied to determine the value of the coefficient of volume compressibility for normally consolidated very soft clay. As in the study area, the coefficient of volume compressibility is given as;

$$m_v = \frac{0.025}{c_u}$$

Substituting the m_v and $B = 1$ into Equation 4 gave;

$$S_c = \frac{0.025}{c_u} \times 0.55q_{all} \times 1.5B = 0.021q_{all}Bc_u^{-1}$$

$$S_c = 0.021q_{all}c_u^{-1} \quad (19)$$

The total settlement S is given as the sum of the immediate and the consolidated settlements, as given in Equation 20.

$$S = q_{all}[0.021 + 0.025(0.45(B/L)^{-0.38})(1 - 0.048(1 + B/L))]c_u^{-1} \quad (20)$$

The allowable maximum settlement of 50mm specified in Eurocode 7 for normal isolated foundations of a building without differential settlement was adopted as the settlement limit. The settlement performance function is given by Equation 21.

$$G = S_L - q_{all}[0.021 + 0.025(0.45(B/L)^{-0.38})(1 - 0.048(1 + B/L))]c_u^{-1} \quad (21)$$

Where $S_L = 50$ mm is adopted for the reliability analysis,

The results of reliability-based design using the First-Order Reliability Method (FORM) and validation using Monte Carlo Simulation (MCS) for the settlement-based criterion are presented in Tables 8, 9, and 10 for $B/L = 0.50, 0.75$, and 1.0 , respectively.

For serviceability criteria, Eurocode specifies a target reliability index of $\beta = 1.5$ for irreversible SLS over a 50-year reference period (European Commission, 2024).

Table 8: Variation of Implied Safety Index with Applied Load for $B/L = 0.50$

B/L = 0.50 $q_u = 134.20 \text{ KPa}$				Target $\beta = 1.5$
FS	Q_{uall}	Beta (FORM)	Beta (MCS)	Performance Level
2.0	67.10	-6.0855	-6.1012	Hazardous
2.5	53.68	-3.4191	-3.4298	Hazardous
3.0	44.73	-1.6409	-1.6491	Hazardous

3.5	38.34	-0.3713	-0.3722	Hazardous
4.0	33.55	0.5804	0.5864	Unsatisfactory
4.5	29.82	1.3215	1.3314	Unsatisfactory
5.0	26.84	1.9136	1.9219	Meet Target

Table 9: Variation of Implied Safety Index with Applied Load for B/L = 0.75

B/L = 0.75 $q_u = 141.43 \text{ KPa}$				Target $\beta = 1.5$
FS	Q_{uall}	Beta (FORM)	Beta (MCS)	Performance Level
2.0	70.72	-5.6003	-5.6201	Hazardous
2.5	56.57	-3.0299	-3.0530	Hazardous
3.0	47.14	-1.3169	-1.3264	Hazardous
3.5	40.41	-0.0943	-0.0951	Hazardous
4.0	35.36	0.8230	0.8269	Unsatisfactory
4.5	31.43	1.5369	1.5511	Meet Target
5.0	28.29	2.1073	2.1227	Meet Target

Table 10: Variation of Implied Safety Index with Applied Load for B/L = 1.0

B/L = 1.00 $q_u = 148.33 \text{ KPa}$				Target $\beta = 1.5$
FS	Q_{uall}	Beta (FORM)	Beta (MCS)	Performance Level
2.0	74.17	-5.8060	-5.8250	Hazardous
2.5	59.33	-3.1945	-3.2195	Hazardous
3.0	49.44	-1.4540	-1.4630	Hazardous
3.5	42.38	-0.2116	-0.2122	Hazardous
4.0	37.08	0.7211	0.7250	Unsatisfactory
4.5	32.96	1.4461	1.4543	Meet Target Marginally
5.0	29.67	2.0251	2.0389	Meet Target

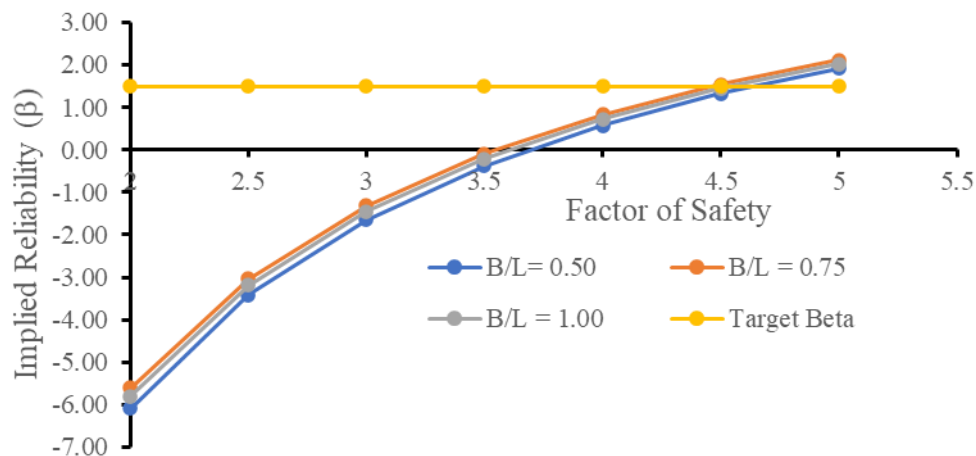


Figure 2 Graph of Settlement Reliability Index (β) versus Factor of Safety

The settlement-based reliability analysis presented in Tables 8-10 and Figure 2 shows a clear monotonic increase in the reliability index (β) with increasing factor of safety (FS) for all footing aspect ratios considered. This indicates that as applied stress decreases relative to bearing resistance, the likelihood of exceeding the allowable settlement limit also decreases. In the uploaded analysis, β increases from strongly negative values at low FS to positive values at higher FS, confirming that serviceability governs design in the soft clay deposit rather than ultimate bearing failure alone. The close agreement between FORM and Monte Carlo Simulation also shows that the probabilistic model is stable and internally consistent.

Footing geometry has a measurable effect on settlement reliability. For the same FS, the near-square footing generally produces a slightly higher β than the more elongated footing, reflecting a more favourable stress distribution beneath the foundation. In the document, β at FS = 5.0 is 1.9136 for B/L = 0.50, 2.1073 for B/L = 0.75, and 2.0251 for B/L = 1.00, indicating that geometry influences serviceability performance but does not override the dominant effect of soil compressibility.

Settlement is most sensitive to soil stiffness and compressibility parameters, especially m_v , and E, because these control immediate and consolidation settlements. In soft normally consolidated clay, even small increases in applied load can produce large settlement changes, so uncertainty in compressibility is usually more important than uncertainty in strength. This is consistent with Eurocode 7, which requires settlement to be treated as a serviceability problem and recognises the influence of immediate, consolidation, and creep settlement on foundation performance (CEN, 2004).

The observed trend agrees with previous settlement reliability studies, which show that serviceability reliability is strongly controlled by allowable settlement and soil compressibility rather than strength alone (Wang & Kulhawy, 2008; Teshager et al., 2025). It also aligns with guidance that settlement in soft clay may continue over time and that differential settlement may be more critical than total settlement in practice (FHWA, 2002; CEN, 2004).

A key implication is that conventional bearing-capacity design may not be sufficient for the site conditions considered. Although the analysis adopts a 50 mm settlement limit and a target reliability index of $\beta = 1.5$, the results show that this target is reached only at relatively high FS values, around 4.5-5.0, depending on the footing geometry. This means that where settlement governs, designers should not rely on shear safety alone. Instead, they should consider larger footing areas, reduced bearing pressure, ground improvement, preloading, or a deep foundation solution where necessary (European Commission, 2024; FHWA, 2002).

4 CONCLUSIONS

The study concludes that the performance of pad foundations on the soft clay deposits of the coastal Niger Delta is controlled primarily by settlement rather than bearing-capacity failure. Although ultimate bearing capacity increased slightly with footing aspect ratio, reliability analysis showed that serviceability requirements governed design, with acceptable reliability achieved only at relatively high factors of safety. The findings demonstrate that conventional deterministic design approaches may not adequately capture the effects of soil variability and uncertainty, making reliability-based design a more rational framework for foundation design in soft deltaic soils.

The results further indicate that foundation safety can be improved through appropriate footing geometry, reduced bearing pressures, and careful consideration of settlement behaviour. For the site investigated, allowable foundation pressures of approximately 30–42 kN/m² are recommended to satisfy both reliability and serviceability requirements. Accurate determination of shear-strength and compressibility parameters through detailed site investigation and laboratory testing is also essential, as these variables exert the greatest influence on foundation performance.

Overall, the research highlights the need for a shift from purely factor-of-safety-based design to reliability-based geotechnical design in the Niger Delta. Future projects on similar soft clay deposits should incorporate probabilistic analyses, detailed settlement assessments, and, where necessary, ground-improvement or alternative foundation solutions to achieve safe, economical, and sustainable foundation performance.

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