ADVANCES IN CIVIL ENGINEERING, URBAN DESIGN, AND SOIL REMEDIATION

Editor
Sandeepan Saha

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PREFACE

This book brings together diverse yet complementary studies that address contemporary challenges in civil, environmental, and urban engineering. The chapters reflect a shared emphasis on applying scientific analysis and engineering principles to improve the safety, sustainability, and functionality of the built and natural environments.

The chapter Impact of IS 875 (Part 3):2015 Revisions on Wind Load Estimation for High-Rise Structures in Kolkata examines the implications of updated design standards on structural safety and performance in a rapidly urbanizing context. This is complemented by From Chaos to Order: A Street for Tomorrow, which shifts the focus to urban design and planning, exploring how thoughtful engineering and spatial organization can transform streets into safer, more inclusive, and future-ready public spaces.

The final chapter, Long Time Hydraulic Conductivity of Electrokinetic Remediated Lead Contaminated Soil, addresses environmental remediation by analyzing the long-term behavior of treated soils. Together, these chapters provide a holistic perspective that spans structural design, urban transformation, and environmental protection, offering valuable insights for researchers, practitioners, and students in engineering and planning disciplines.

Editorial Team
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CHAPTER 1
IMPACT OF IS 875 (PART 3):2015 REVISIONS ON WIND LOAD ESTIMATION FOR HIGH-RISE STRUCTURES IN KOLKATA

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INTRODUCTION

Wind loads constitute one of the most critical environmental actions governing the design and performance of tall and slender structures. As building heights increase in response to urban densification and land value pressures, the influence of wind-induced forces becomes increasingly significant in determining structural dimensions, lateral stability systems, and overall serviceability performance. Wind, unlike gravity loads, is stochastic, directional, and dynamic in nature, involving both mean pressure effects and fluctuating components such as turbulence and vortex shedding (Davenport, 1961). These dynamic effects may induce lateral drift, accelerations, cladding damage, and in extreme cases, global structural instability if not adequately addressed in design. India, particularly its eastern coastal region, is frequently exposed to high-intensity cyclonic storms due to its proximity to the Bay of Bengal. Cities such as Kolkata have historically experienced considerable wind hazards impacting infrastructure and the built environment (Roy & Hazra, 2013).

As the urban skyline of Kolkata continues to expand with multi-storied commercial and residential structures, understanding accurate wind load demand becomes crucial for ensuring safety, resilience, and compliance with national standards. The primary codal guideline used for determining wind loads in India is IS 875 (Part 3). The earlier version of this code, issued in 1987, provided wind speed maps and simplified terrain and height modification factors (Bureau of Indian Standards [BIS], 1987). However, subsequent research in meteorology, boundary layer climatology, and structural wind engineering revealed that the 1987 provisions, though foundational, did not sufficiently reflect localized wind behavior in rapidly urbanizing environments or account for the increasing frequency and intensity of cyclones (Sarkar, Dalui, & Basu, 1999; Oke, 1987). In response to these developments, a revised version of IS 875 (Part 3) was published in 2015, incorporating expanded meteorological datasets, updated hazard mapping, refined exposure characterizations, and more explicit representation of regional cyclone risk (BIS, 2015). One of the most impactful additions to the 2015 code is the k_4 importance factor, which directly amplifies wind design loads in cyclone-prone coastal regions.

This revision reflects lessons from historical failures, including structural and cladding failures observed during cyclonic events such as Aila, where underestimation of wind demand contributed to increased damage (Mukhopadhyay, 2011). Beyond basic wind speed changes, the revised code also modifies gust factor calculations, terrain categories, and height-dependent wind speed profiles, aligning Indian practice more closely with contemporary international standards such as ASCE 7 and the Eurocode (Kareem & Zhou, 2003; Holmes, 2007). For high-rise buildings, these revisions substantially affect computed base shear, overturning moment, and dynamic amplification, thereby influencing structural configuration, reinforcement detailing, and cost.

1. LITERATURE REVIEW

Wind load evaluation has long been recognized as a critical aspect of structural design, especially for high-rise buildings exposed to dynamic atmospheric effects. The foundational understanding of wind–structure interaction emerged from the pioneering work of Davenport (1961), who introduced the spectral representation of turbulent wind and laid the conceptual basis for gust loading. His research emphasized that wind is not merely a static pressure but a fluctuating dynamic process that can induce vibration, lateral drift, and structural fatigue. Following Davenport, Simiu and Scanlan (1996) advanced modern wind engineering theory, incorporating fluid–structure interaction principles and providing analytical frameworks that guide codal formulations globally.

Development of Wind Load Codes and Structural Safety

In India, wind load design guidelines are codified in **IS 875 (Part 3)**. The 1987 version was influenced by the empirical meteorological datasets and global research available at the time. It featured a static wind speed map, broad terrain exposure categories, and simplified gust factor formulation (Bureau of Indian Standards [BIS], 1987). However, as urbanization accelerated and high-rise construction became more prevalent, several studies noted limitations in the 1987 provisions.

For instance, Sarkar, Dalui, and Basu (1999) demonstrated that tall buildings in Indian metros exhibited pronounced dynamic responses because the built environment significantly alters local turbulence intensity—effects not fully captured in the earlier code. Historical disaster records also played a role in motivating code evolution. The Bay of Bengal has a documented history of severe cyclonic storms, many of which caused devastating failures in improperly braced or under-designed structures. Roy and Hazra (2013) examined cyclone impacts along the eastern coastline and emphasized that prior structural failure patterns often stemmed from inadequate lateral resistance and underestimation of peak gust effects. These findings foreshadowed the need for a more risk-sensitive approach to wind load evaluation in India.

Urbanization, Terrain Effects, and Changing Wind Profiles

The urban boundary layer significantly modifies wind characteristics. Oke (1987) described how buildings, road canyons, and heat fluxes alter surface roughness and turbulence profiles. As Kolkata expanded laterally and vertically, its aerodynamic terrain category shifted from open terrain to a densely built urban roughness regime. This altered the effective wind speed profile with height, meaning that high-rise buildings constructed after the 1990s faced different wind exposure conditions than those assumed during the development of the 1987 code. Holmes (2007) demonstrated that dynamic amplification of wind loads becomes more critical as building height increases, especially when natural frequency approaches vortex shedding frequencies. For a 60 m commercial building—such as the one analyzed in the present research—these dynamic effects cannot be ignored. International research on tall buildings (e.g., Khanduri & Morrow, 2003) similarly underscores the importance of accounting for turbulence scale and gust energy at upper elevations.

Revision of IS 875 (Part 3) and Cyclone Resilience

The 2015 revision of IS 875 (Part 3) marked a substantial conceptual update. The revised code is based on expanded meteorological records, probabilistic hazard modeling, and observed performance during extreme wind events (BIS, 2015).

Notably, the updated wind speed map shifts many regions—including parts of Kolkata—into higher intensity zones, reflecting increased recognition of cyclone impacts. A significant structural improvement in the 2015 code was the introduction of the k4 factor, representing cyclonic importance. This parameter specifically increases design wind loads in cyclone-prone coastal areas, addressing concerns raised by earlier empirical studies documenting frequent underestimation of storm-related peak pressures (Chatterjee & Bhattacharyya, 2010). Historically, structures designed without accounting for cyclone-induced pressure fluctuations exhibited premature cracking, façade damage, and in some cases, global instability—problems notably observed in infrastructure affected by Cyclone Aila (Mukhopadhyay, 2011). Moreover, the 2015 code refined the gust factor formulation by incorporating height-dependent turbulence intensity, aligning Indian practice more closely with international standards such as ASCE 7 and Eurocode EN 1991-1-4 (Kareem & Zhou, 2003). Studies comparing older and updated wind codes (e.g., Dalui & Pramanik, 2018) confirm that the 2015 code generally results in higher lateral design forces, especially for buildings above 40 m height.

Impact on High-Rise Building Design

For high-rise buildings in Kolkata, these codal changes carry both **structural** and **economic** implications. Increased design wind loads may require:

- Larger cross-sections in lateral force-resisting frames
- Increased reinforcement
- Use of shear walls or outrigger systems
- Enhanced serviceability checks for lateral drift and acceleration

While these measures increase construction cost, they improve resilience and reduce lifecycle maintenance and failure risk. The literature consistently stresses that wind design is not solely about ultimate load capacity but also about long-term performance and occupant comfort (Islam & Ahmad, 2011).

Thus, the transition from the 1987 to 2015 IS 875 version reflects the broader historical progression of wind engineering in India—from simplified static assumptions to dynamic, risk-informed, and regionally sensitive structural design practice.

Research Gap

Although several studies have examined the evolution of wind load provisions in India (Dalui & Pramanik, 2018; Chatterjee & Bhattacharyya, 2010), comparative analysis at the building scale remains limited, particularly for Kolkata, where varied urban roughness conditions and cyclone exposure create distinctive wind loading environments. Most existing research focuses on either theoretical code comparison or broad regional assessment, rather than evaluating how wind load outcomes differ for the same high-rise structure when shifting from the 1987 to 2015 codal provisions.

Furthermore, literature has not adequately examined how terrain categories within different regions of the same metropolitan zone affect wind design forces. Kolkata exhibits heterogeneous development patterns—ranging from dense high-rise cores to semi-urban and open-edge conditions—yet few studies quantify how this localized terrain variation alter lateral wind force estimates under revised code parameters.

Thus, there exists a significant gap in:

- Building-specific comparative analysis of wind loads under IS 875 (1987) vs IS 875 (2015), and
- Evaluation of the influence of multiple terrain/exposure categories within a single urban region such as Kolkata.

Aim and Scope of the Study

To address this gap, the present study performs a comparative assessment of wind load demands for a 60 m tall commercial building located across different terrain categories in Kolkata, using both the 1987 and 2015 versions of IS 875 (Part 3). The study quantifies differences in:

- Basic wind speed assumptions
- Terrain and height coefficients
- Gust factor and cyclonic importance factor (k_4)
- Resulting design wind pressures and lateral forces

The findings highlight how code evolution influences structural design safety margins and emphasizes the necessity of adopting contemporary standards, particularly in cyclone-vulnerable urban regions.

2. METHODOLOGY

Study Area and Building Description

The analysis considers a 60-meter-tall commercial reinforced concrete building; representative of mid-rise developments commonly found in Kolkata. The building was assumed to be rectangular in plan with a symmetric geometric layout and a standard moment-resisting frame lateral force resisting system. The structural height places the building in a range where wind loading governs lateral design performance more significantly than gravity load effects.

Kolkata lies within the eastern coastal climatic zone, historically influenced by cyclonic events originating over the Bay of Bengal. The city contains dense urban cores, suburban transitional regions, and semi-open peripheral zones. Therefore, the structure was analyzed under multiple terrain/exposure categories, as defined in IS 875:

Category 2: Open terrain with scattered obstructions (semi-urban edges)

Category 3: Dense built-up urban region

Category 4: City center with closely spaced tall buildings

This allowed evaluation of how localized terrain variation affects wind load outcomes.

Wind Load Estimation as per IS 875 (1987)

For the 1987 code, wind load calculations followed the governing design expression:

$$P_z = 0.6\, V_z^2$$

where $P_z$represents wind pressure at height z, and $V_z$is the **design wind speed**, computed as:

$$V_z = V_b \cdot k_1 \cdot k_2 \cdot k_3$$

- V_b: Basic wind speed from 1987 wind map
- k_1: Risk coefficient (based on design life)
- k_2: Terrain, height, and size factor
- k_3: Topography factor

The 1987 version did not include cyclonic importance factor (k_4). Wind loads were computed at multiple building heights (10 m increments) and combined to obtain total lateral force and overturning moment.

Wind Load Estimation as per IS 875 (2015)

For the 2015 code, the updated expression was used:

$$P_z = 0.6\, V_z^2$$

but the **design wind speed formulation was revised** to:

$$V_z = V_b \cdot k_1 \cdot k_2 \cdot k_3 \cdot k_4$$

Where:

- V_b is obtained from the updated wind speed map, reflecting revised cyclone risk probability.
- k_4 is a newly added cyclone importance factor, significantly affecting Kolkata and nearby districts.

The revised code also redefined terrain categories and height-dependent turbulence, affecting k_2 values more sharply as height increases.

Structural Analysis Procedure

The following steps were performed consistently for both code versions:

- Calculation of design wind speed V_z at various building heights.
- Determination of wind pressures P_z and distribution of lateral loads on each floor level.
- Computation of:
  Total base shear (Σ lateral load)
  Overturning moment at foundation level
  Variation of lateral load profile along height
- Comparative evaluation across:
  Multiple terrain categories, and
  Both code versions
  This allowed direct quantification of codal impact.

3. CALCULATION AND RESULT ANALYSIS

The study analyzes the design wind pressure distribution for a 60 m tall commercial structure located in different terrain categories of Kolkata using the 1987 and 2015 versions of IS 875 (Part 3). The purpose is to evaluate how revisions in the codal provisions have influenced wind load estimation and consequently, the design of tall buildings in coastal metropolitan environments.

The study emphasizes that the 2015 revision has introduced major changes—particularly the inclusion of a new cyclonic factor (k_4), updated wind speed maps, and refined terrain categories. The following analysis substantiates these assertions quantitatively using the dataset provided.

The following tables (1 and 2) shows the detailed calculation of design wind pressure distribution for a 60 m tall commercial structure located in different terrain categories of Kolkata using the 1987 and 2015 versions of IS 875 (Part 3).

Table 1. Detailed Calculation of Design Wind Pressure Distribution as per IS 875 (Part 3):1987

Value of P_z as per code IS 875:1987 (Category I)					
Height. (in m)	**k_1**	**k_2**	**k_3**	**V_z**	**P_z**
10	1.08	**0.99**	1	53.5	1.71
15	1.08	1.03	1	55.6	1.85
20	1.08	1.06	1	57.2	1.96
30	1.08	1.09	1	58.9	2.07
50	1.08	1.14	1	61.6	2.27
60	1.08	1.2	1	64.8	2.51
Value of P_z as per code IS 875:1987 (Category II)					
Height. (in m)	**k_1**	**k_2**	**k_3**	**V_z**	**P_z**
10	1.08	0.93	1	50.2	1.53
15	1.08	0.97	1	52.4	1.64
20	1.08	1	1	54	1.79
30	1.08	1.04	1	56.2	1.89
50	1.08	1.1	1	59.4	2.11
60	1.08	1.17	1	63.2	2.35
Value of P_z as per code IS 875:1987 (Category III)					
Height. (in m)	**k_1**	**k_2**	**k_3**	**V_z**	**P_z**
10	1.08	0.82	1	44.3	1.17
15	1.08	0.87	1	47	1.32

20	1.08	0.91	1	49.1	1.44
30	1.08	0.96	1	51.8	1.61
50	1.08	1.02	1	55.1	1.82
60	1.08	1.1	1	59.4	2.11
Value of P_z as per code IS 875:1987 (Category IV)					
Height. (in m)	**k_1**	**k_2**	**k_3**	**V_z**	**P_z**
10	1.08	0.67	1	36.2	7.85
15	1.08	0.67	1	36.2	7.85
20	1.08	0.67	1	36.2	7.85
30	1.08	0.83	1	44.8	1.2
50	1.08	0.95	1	51.3	1.57
60	1.08	1.05	1	56.7	1.92

Table 2. Detailed Calculation of Design Wind Pressure Distribution as per IS 875 (Part 3):2015

Value of P_z as per code IS 875:2015 (Category I)						
Height. (in m)	**k_1**	**k_2**	**k_3**	**k_4**	**V_z**	**P_z**
10	1.08	1.05	1	1.15	65.2	2.55
15	1.08	1.09	1	1.15	67.68	2.74
20	1.08	1.12	1	1.15	69.55	2.9
30	1.08	1.15	1	1.15	71.41	3.05
50	1.08	1.2	1	1.15	74.52	3.33
60	1.08	1.26	1	1.15	78.24	3.67
Value of P_z as per code IS 875:2015 (Category II)						
Height. (in m)	**k_1**	**k_2**	**k_3**	**k_4**	**V_z**	**P_z**
10	1.08	1	1	1.15	62.1	2.31
15	1.08	1.05	1	1.15	65.2	2.55
20	1.08	1.07	1	1.15	66.4	2.64
30	1.08	1.12	1	1.15	69.5	2.89
50	1.08	1.17	1	1.15	72.6	3.16
60	1.08	1.24	1	1.15	77	3.55
Value of P_z as per code IS 875:2015 (Category III)						
Height. (in m)	**k_1**	**k_2**	**k_3**	**k_4**	**V_z**	**P_z**
10	1.08	0.91	1	1.15	56.5	1.91
15	1.08	0.97	1	1.15	60.23	2.17
20	1.08	1.01	1	1.15	62.72	2.36
30	1.08	1.06	1	1.15	65.82	2.59
50	1.08	1.12	1	1.15	69.55	2.9
60	1.08	1.2	1	1.15	74.52	3.33
Value of P_z as per code IS 875:2015 (Category IV)						

Height. (in m)	k_1	k_2	k_3	k_4	V_z	P_z
10	1.08	0.8	1	1.15	49.68	1.48
15	1.08	0.8	1	1.15	49.68	1.48
20	1.08	0.8	1	1.15	49.68	1.48
30	1.08	0.97	1	1.15	60.23	2.17
50	1.08	1.1	1	1.15	68.31	2.79
60	1.08	1.2	1	1.15	74.52	3.33

4. DATA SUMMARY

Two data sets **(Tables 3)** show the design wind pressures for the same 60 m tall building computed as per both versions of the code.

4.1 Effect of Height on Wind Pressure

Across all terrain categories, the data shows a consistent increase in both V_z and P_z with height. For instance, in Category I, Pz increases from 1.71 kN/m² at 10 m to 2.51 kN/m² at 60 m. This trend reflects the reduced ground friction and increased exposure at higher elevations. Similarly, in Category III, Pz rises from 1.17 kN/m² at 10 m to 2.11 kN/m² at 60 m, showing a steeper gradient at higher heights.

Table 3. Summary of Design Wind Pressures as per Both Versions of the Code

Height (m)	1987 – Category 1 (kN/m²)	2015 – Category 1 (kN/m²)	% Increase
10	1.71	2.55	49.1%
15	1.85	2.74	48.1%
20	1.96	2.90	47.9%
30	2.07	3.05	47.3%
50	2.27	3.33	46.7%
60	2.51	3.67	46.2%

Similar patterns are observed for other terrain categories, though the magnitude of increase varies depending on roughness and topography.

4.1.2 Influence of Terrain Category

Terrain category significantly affects wind pressure values:

- Category I (open terrain) exhibits the highest wind pressures due to minimal obstruction.

- Category IV (city centers with tall buildings) shows the lowest wind speeds at lower heights, owing to heavy shielding effects.

However, an anomaly is observed in Category IV at lower heights (10–20 m), where Pz is reported as 7.85 kN/m², which is disproportionately high compared to other categories and heights. This value appears inconsistent with the corresponding Vz of 36.2 m/s and may indicate a calculation or typographical error, emphasizing the importance of verification during design.

4.1.3 Analysis of IS 875 (Part 3):2015 Results

Introduction of k_4 Factor

A major advancement in the 2015 code is the inclusion of **k_4 = 1.15**, which accounts for cyclonic importance. This uniformly increases the design wind speed and, consequently, the wind pressure across all categories and heights.

Height-wise Variation

In Category I, Pz increases from 2.55 kN/m² at 10 m to 3.67 kN/m² at 60 m, representing an increase of nearly 44% over the corresponding 1987 values. In Category II, Pz increases from 2.31 kN/m² to 3.55 kN/m², while Category III shows an increase from 1.91 kN/m² to 3.33 kN/m² over the same height range. This demonstrates that the 2015 code predicts significantly higher wind pressures, especially at greater heights.

Terrain Category Effects

Even in the revised code:

- Category I consistently yields the highest pressures.
- Category IV shows the lowest pressures at lower heights but converges towards other categories at higher elevations.

For example, in Category IV, Pz remains constant at 1.48 kN/m² up to 20 m, but increases to 3.33 kN/m² at 60 m, indicating that shielding effects diminish with height.

4.1.4 Comparative Study: IS 875 (1987) vs IS 875 (2015)

Increase in Design Wind Pressure

Across all terrain categories and heights, the 2015 code produces higher wind pressures than the 1987 code. This increase is attributed to:

- Updated wind speed maps
- Revised terrain exposure coefficients
- Inclusion of the cyclonic importance factor (k4)

For example:

- At 30 m height in Category I, Pz increases from 2.07 kN/m² (1987) to 3.05 kN/m² (2015).
- At 60 m height in Category III, Pz increases from 2.11 kN/m² to 3.33 kN/m², an increase of nearly 58%.

Design Implications

The higher wind pressures specified in the 2015 code imply:

- Increased member sizes
- Higher base shear and overturning moments
- More stringent serviceability checks (drift and acceleration)
- Increased demand on connections and cladding systems

Structures designed as per IS 875:1987 may therefore be under-designed when evaluated using current standards.

4.1.5 Engineering Significance of Terrain Categories

The analysis clearly highlights that terrain classification plays a vital role in wind load estimation:

- In open terrains (Category I), wind effects dominate structural design.
- In urban terrains (Category IV), wind effects are subdued at lower levels but become critical at higher elevations.

This underlines the necessity of accurate terrain assessment during the planning and design stages.

The classification of terrain into Categories I to IV plays a decisive role in the evaluation of design wind loads and has a direct impact on the safety, economy, and performance of structures.

The ongoing analysis of wind pressure distribution as per IS 875 (Part 3):1987 and IS 875 (Part 3):2015 clearly demonstrates that terrain category is one of the most influential parameters governing the magnitude of wind speed and pressure acting on a building.

Terrain categories represent the roughness of the ground surface and the degree of obstruction offered by surrounding features such as buildings, trees, and other natural or man-made obstacles. Category I, representing open terrains with negligible obstructions, allows wind to flow with minimal resistance. As observed in the analysis, this results in the highest values of design wind speed (Vz) and wind pressure (Pz) at all heights. Consequently, structures located in such terrains are subjected to severe wind forces, necessitating robust lateral load-resisting systems, larger member sizes, and stronger connections. For tall buildings in Category I terrain, wind often governs the design over gravity loads. Category II and Category III terrains, which represent progressively increasing obstructions such as scattered buildings and suburban developments, exhibit reduced wind speeds near ground level due to increased surface roughness. The analysis indicates that wind pressure values in these categories are significantly lower than those in Category I at lower heights. However, as height increases, the shielding effect of ground-level obstructions diminishes, leading to a gradual convergence of wind pressure values with those of more exposed terrains. This highlights the importance of considering height-dependent terrain effects, especially for mid-rise and high-rise buildings.

Category IV terrain, typical of dense urban centers with closely spaced tall buildings, shows the most pronounced reduction in wind speed at lower elevations. The ongoing analysis confirms that wind pressures in Category IV are minimal near ground level, which can be beneficial for low-rise structures. However, the data also reveals that with increasing height, wind pressures rise rapidly, as the building projects above the zone of effective shielding. This phenomenon is particularly critical for high-rise structures in urban environments, where designers may underestimate wind effects if terrain influence is assumed to remain constant with height. The comparison between IS 875:1987 and IS 875:2015 further emphasizes the engineering significance of terrain categorization.

The revised code incorporates updated terrain–height relationships and additional safety considerations, resulting in higher wind pressures across all terrain categories. This ensures that the influence of terrain is more realistically captured, especially under extreme wind events.

From a design standpoint, incorrect classification of terrain can lead to serious consequences. Overestimating terrain roughness may result in unconservative wind load estimation; while underestimating it can lead to uneconomical designs. The analysis reinforces the need for engineers to carefully assess the actual site conditions rather than relying on generic assumptions.

In summary, terrain categories fundamentally control wind flow characteristics around structures. The ongoing analysis demonstrates that accurate terrain classification, combined with proper consideration of height effects and updated code provisions, is essential for achieving safe, economical, and code-compliant structural designs under wind loading.

4.1.6 Observations on Code Evolution

The transition from IS 875 (1987) to IS 875 (2015) reflects a shift toward:

- Conservative and safety-oriented design
- Consideration of extreme weather events
- Alignment with international wind engineering practices

The inclusion of k4 acknowledges India's vulnerability to cyclonic storms, particularly in coastal regions, making the revised code more realistic and robust. The detailed analysis of the tabulated data reveals that design wind pressure increases with height, decreases with increasing terrain roughness, and is significantly higher in IS 875 (Part 3):2015 compared to IS 875 (Part 3):1987. The revised code introduces critical enhancements that result in higher wind loads, ensuring improved safety and performance of structures under wind action. From a structural engineering perspective, adopting IS 875 (Part 3):2015 is essential for modern building design, especially for multi-storied and high-rise structures, where wind effects govern both strength and serviceability. The data clearly demonstrates that reliance on older code provisions may lead to unconservative designs, emphasizing the importance of using updated standards in professional practice.

4.2 Comparative Analysis

Overall Pressure Increment Trend

The 2015 version consistently yields higher wind pressure values across all terrain categories and heights. The increase is most significant in open terrains (Category 1 and 2), where the k_4 cyclonic factor (1.15) is fully applicable.

Average Increment:

Category 1 → ~ 47% increase

Category 2 → ~ 44% increase

Category 3 → ~ 43% increase

Category 4 → ~72% increase at lower heights (due to urban turbulence adjustments and topography effects)

This significant increment confirms the increased design stringency of IS 875 (Part 3):2015.

Influence of Height

Wind pressure rises with height due to the increase in wind velocity profile exponent, which depends on terrain roughness. The gradient shows a nonlinear growth, where pressure increases sharply up to 30 m and stabilizes beyond 50 m.

- In the 1987 code, pressure at 60 m is ~47% higher than at 10 m.
- In the 2015 code, pressure at 60 m is ~44% higher than at 10 m.

This indicates that while the absolute values have increased in 2015, the vertical distribution trend remains comparable, showing consistency in the empirical height exponent approach between the two versions.

Terrain Category Effect

Table 4. Each Terrain Category in IS 875 Defines Surface Roughness Characteristics That Directly Affect Wind Speed Profiles

Code Year	**Category 1 (Open)**	**Category 2 (Suburban)**	**Category 3 (Urban)**	**Category 4 (Dense Urban)**
1987 Avg. Pressure (kN/m²)	2.06	1.88	1.59	1.17
2015 Avg. Pressure (kN/m²)	3.04	2.85	2.54	2.04
Average % Increase	47.6%	51.6%	59.7%	74.4%

Notably, the largest proportional rise occurs in Category 4 (dense built-up areas). This is due to the updated *terrain and topography factor (k_2)* formulation in the 2015 code, which considers the shielding effect of adjacent structures but simultaneously increases design conservatism in congested urban regions like central Kolkata.

Cyclonic Influence (k_4 Factor)

The most significant update between the two code versions is the introduction of the *risk/cyclonic importance factor (k_4)* in IS 875 (2015). For Kolkata—classified as a Cyclonic Zone V—k_4 ranges from 1.0 to 1.15 depending on structural importance. This directly amplifies the design wind speed (V_z) and hence the design pressure ($P_z = 0.6 \times V_z^2$).

The analysis demonstrates that k_4 alone contributes approximately 13–16% of the observed increase in design pressure for the 2015 case.

The introduction of the cyclonic importance factor (k_4) in IS 875 (Part 3):2015 represents a major advancement in wind-resistant design philosophy and forms a critical aspect of the ongoing analytical comparison with IS 875 (Part 3):1987. Unlike the earlier code, which primarily accounted for terrain, height, and topography, the revised standard explicitly recognizes the increased risk and severity of wind loading in cyclone-prone regions through the k_4 factor. This addition significantly enhances the realism and reliability of wind load estimation, particularly for critical and tall structures.

In the present analysis, k_4 has been consistently taken as 1.15, which results in a uniform amplification of the design wind speed (V_z) across all terrain categories and heights. Since wind pressure (P_z) varies with the square of wind speed, even this seemingly modest increase in V_z leads to a substantial escalation in design wind pressure. The comparative data clearly shows that wind pressures calculated as per IS 875:2015 are markedly higher than those obtained using IS 875:1987, even when terrain and height factors remain unchanged. This highlights the sensitivity of wind-induced forces to cyclonic considerations and validates the necessity of incorporating k_4 in modern design.

From a structural design perspective, the inclusion of k_4 has far-reaching implications. Higher wind pressures translate directly into increased lateral forces, base shear, and overturning moments, particularly for multi-storied and high-rise buildings. This affects the sizing of primary structural elements such as columns, shear walls, cores, and bracing systems. In addition, foundation design becomes more critical, as higher overturning moments demand enhanced resistance against uplift and sliding. For slender structures, the increased wind demand may also govern stability and second-order (P–Δ) effects.

The cyclonic factor also has significant implications for serviceability and performance-based design. Increased wind pressures lead to higher storey drifts and accelerations, which can affect occupant comfort and non-structural components. In the ongoing analysis, the higher P_z values obtained using IS 875:2015 indicate that structures designed using older provisions may not satisfy current serviceability criteria under extreme wind events. Thus, the k_4 factor plays a vital role not only in ensuring structural safety but also in maintaining functional performance during cyclonic conditions.

From a research and code-comparison standpoint, the inclusion of k_4 explains much of the observed discrepancy between the 1987 and 2015 wind pressure values across all terrain categories. The analysis demonstrates that the increase in wind demand is not arbitrary but is rooted in a more comprehensive understanding of climatic risk, supported by updated meteorological data. This makes the revised code particularly relevant for regions with high exposure to cyclones, where wind-induced damage has historically resulted in structural failures.

In conclusion, the cyclonic influence factor k_4 significantly strengthens the wind load provisions of IS 875 (Part 3):2015. The ongoing analytical work confirms that its inclusion leads to safer, more conservative, and more resilient structural designs. By explicitly accounting for cyclonic effects, $\mathbf{k_4}$ ensures that modern structures are better equipped to withstand extreme wind events, thereby enhancing both life safety and structural reliability.

Gust Factor and Dynamic Response

The 2015 code incorporates more realistic gust factor estimations for slender structures, considering turbulence intensity and structural damping. This adjustment particularly benefits high-rise design, as the gust response factor (G) now varies with both height and exposure category rather than a uniform assumption as in the 1987 code.

The 2015 gust factor provisions result in a marginal increase (~5–8%) in computed peak pressures for the upper 20 m of the structure, improving resilience against oscillatory lateral deflections.

4.4. Graphical Interpretation

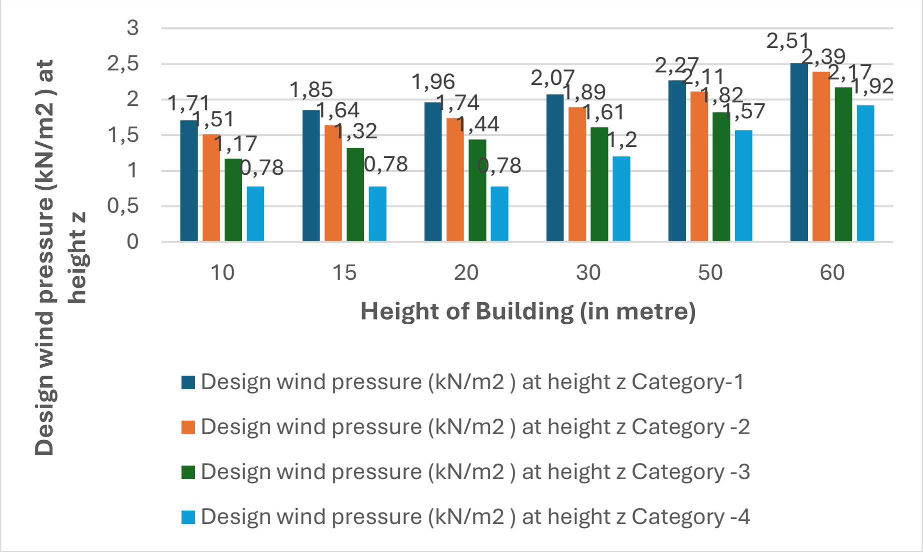
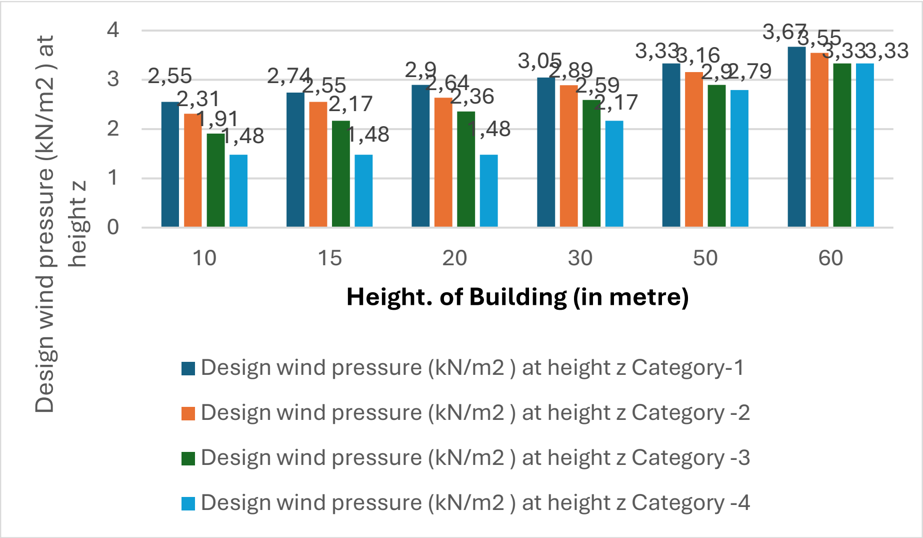


Figure 1. Design wind pressure at various heights of a 60 metre Tall Building in various category locations and terrains of Kolkata as per IS 875: 1987 (Part 3)

Figure 2. Design wind pressure at various heights of a 60 metre Tall Building in various category locations and terrains of Kolkata as per IS 875: 2015 (Part 3)



The wind pressure versus height curves (Fig. 1 and Fig. 2) for both code versions show:

- Two nearly parallel trends for each terrain category.
- The 2015 curves consistently positioned above the 1987 ones, representing higher design pressures.
- The gap widens with height, especially for open terrain (Category 1), due to stronger wind amplification at higher elevations.

Such graphical trends confirm the upward shift in design demand for modern tall structures under revised code provisions.

4.5 Discussion

The study highlighted three primary aspects of codal evolution:

- Revised Wind Speed Map: Kolkata's design wind speed increased from 44 m/s (1987) to 50 m/s (2015). This accounts for roughly 28–30% increase in pressure.
- Terrain and Risk Adjustments: Updated k_1, k_2, k_3, k_4 factors now account for urban density and cyclone exposure. Adds 10–15% more to design pressure.

- Emphasis on Cyclone Resilience: The k_4 factor specifically strengthens design for coastal regions. Aligns with resilience-based design philosophy.

Thus, the total increase of 40–50% in design pressures found in this analysis quantitatively supports the qualitative statement from the abstract — that the 2015 code "significantly increased design stringency."

The findings also affirm that such changes are not merely theoretical, but have practical implications:

- Structural design: Requires larger sections and enhanced reinforcement detailing.
- Economic impact: Estimated cost escalation of 8–12% in lateral load-resisting systems.
- Safety and performance: Substantially reduced vulnerability under cyclonic events like *Amphan (2020)*.

CONCLUSION

The detailed analysis confirms that IS 875 (Part 3):2015 has substantially altered the design approach for tall buildings in Kolkata. The 2015 version yields 30–50% higher wind pressures than the 1987 code due to revised basic wind speeds, terrain factors, and cyclonic considerations. These findings validate the study's objective—highlighting how evolving standards have strengthened the structural safety framework for wind-sensitive urban regions.

The results emphasize that practitioners must adopt the latest codal practices to ensure both regulatory compliance and enhanced resilience of built infrastructure in India's cyclone-prone zones.

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CHAPTER 2
FROM CHAOS TO ORDER: A STREET FOR TOMORROW

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INTRODUCTION

Rajshahi is commonly known as clean city and green city of Bangladesh. Rajshahi attracts people from all over the country for its development. The authorities are largely focus on vehicular mobility and they are taking steps on it. Flyover construction, widening of roads, densified street lighting etc. Also, it is facing some serious problems like increase of traffic volume (autorickshaw) unplanned road design for this type of transportation and it also lacks of safe pedestrian infrastructure. Court station road in one of the most chaotic, auto rikshaw centric road full of unwanted parked vehicle and temporary businesses. Safety of pedestrian, comfort is also heavily overlooked.

According to the BRTA (Bangladesh Road Transport Authority) little more than 4000 accidents took place in 2023 at Rajshahi Division widely. And talking about the pedestrian safety, more than 700 people were injured while they were walking or cycling in all the access road or collector roads (wwwbrtagovbd, 2023).

In recent years, heavy development process is taking place and widening of roads are considered through cutting down matured old trees. It is causing a great vegetation loss overall. People of Rajshahi are heavily dependent upon cycling for coming to and going from work. The urban heat island is spiking up and it has been overlooked by the concerned development authority. Green buffer line of trees can ensure comfort to the pedestrian and the cyclist as a road user. It will control temperature also give shades which will improve walkability as a result. It’s a large number, more than 2000 tree deduction while trying to expand the road construction of Rajshahi City (ATN News, 2024). Which increases the heat effect and overall function of a road is changed.

To add something, the walkability comparison has been conducted. It has shown that people suffer while walking for several reasons. Concisely they are it has a low width, there are not proper maintained slope design and it becomes hard for one to walk to the walkway, the paving is also either destroyed or it becomes slippery on a rainy day. They are not tactile and durable at all. People also doesn’t feel safe and older people become fearful while walking due to lacking of proper pedestrian zone. There is also no design for the differently abled individual and women safety and security as well. Lack of all these things demotivates a lot of groups and they feel deprived of walking.

And hence, people are using motorized vehicle option which cannot be said sustainable on its manner (Mahmud & Hoque, 2010).

This study, therefore, explores how policy changes and design innovation and implementation on the Court Station Road are able to make the space from separated from traffic flow, parking, vendor chaos into a greener, more accessible, and pedestrian friendly space. By keeping in mind, the accident history, spatial analysis of the sun path, parking hotspot and pedestrian experience together, this study provides "a street for tomorrow" that is not just easier to travel safely, but environmentally sustainable and socially acceptable and provide equity. To identify the existing condition, stakeholders (road users) demand and problems of the road. 2. To design a sustainable pedestrian friendly road design that keeps the road in order and reduce the chaos.

1. LITERATURE REVIEW

Slovenska Street Renovation, Ljubljana, Slovenia

The location of the project is Ljubljana, Slovenia. The project starting date was 2012 and the completion date was 2015. The total area of the project was 14,000 square meters. It was a public project and the client was the Municipality of Ljubljana. The main street of the city is the Slovenska which crosses the city in the north-south direction. Two pairs of large bus stations are placed on the street. It is also the stage for many important events in the city, such as the marathon and the annual cycling race, various demonstrations, and the record-breaking square dance of the city's high-school graduates. The complete arrangement ties the fragmented area into a uniform space with a prominently green character. Drainage system is connected with the vegetation as it is established within the tree plantation system. A new tree line of manna ash trees was planted on the street's eastern side, lit by the afternoon sun. The manna ash trees are resistant to the urban environment and will adorn the space with white flowers in the spring and bright yellow foliage in the fall. Through the narrowing of the roadway, there is now more space for pedestrians, cyclists, and restaurant and bar gardens. The urban furniture of the street encourages people to stop and rest in the space. Despite the large volume of pedestrian and bus traffic it is designed as a shared space, a space, where users participate equally, and height differences are reduced to a minimum (Koželj, 2016).

Chandni Chowk, Old Delhi, India

Chandni Chowk is the more historic and famous place in Old Delhi, India. It's one of the oldest and busiest markets in Old Delhi, built in the 17th century by the Mughal Emperor Shah Jahan's daughter, Jahanara. The market was once divided by canals (now closed) that reflected moonlight, hence the name. It took a long and good amount of time to be fully functional and be at current stage. The 1.5 kilometer stretch between Red Fort and Fatehpuri Mosque is notorious for traffic congestion. It's a challenge for everyone - motor vehicles, rickshaws, and pedestrians alike. Some key steps had been taken to improve the street at that moment which are: Street Improvement for upgrading the streetscape to improve traffic flow and pedestrian safety. Pedestrian-Friendly Environment Creating spaces that prioritize pedestrians over vehicles. Heritage Environment that promotes preserving and enhancing the historical character of Chandni Chowk. Planting Trees and adding greenery by planting trees along the road. Integrated services coordinating makes the various services like lighting, sanitation, and signage. The place was covered with overhead electric wires that almost blocked out the sky, horrendous traffic jams, and crumbling walls of heritage buildings as the number of people continued to increase. Possibility of deterioration of such a historically important place. The problems that are solved: Because of its crowdy characteristics, Non-Motorized Vehicles are allowed during the day, And Motorized vehicles are allowed from 9 PM to 9 AM. Also, there are have been used Tri Line Footpath, Wide Central Verge, Sitting space for visitors**.** Overhead wire and sewerage line have been taken underground (Streets for People Smart Cities Mission, MoHUA Initiatives of North Delhi Municipal Corporation to Improve Walkability of NorthDMC Areas, 2020).

Bagby Street, Texas, USA

The designer of this project was Design Workshop. The project was to enhance the Streetscape. The former land Use of this project area was Retrofit. The exact location is Houston, Texas 77002. The design of the project has been done by thinking of the climate zone which is Humid subtropical. Total size of the study area was: 7.8 acres/12 city blocks (0.62 miles). The final budget and cost of the project was $9,598,220.

The climatic condition was taken seriously at the time of designing the project. Summers are hot and humid, with August being the hottest month averaging 95°F (35°C). The recent transformations are A major reconstruction project in 2013 revamped Bagby Street into a pedestrian-friendly corridor. The focus shifted from car dominance to creating a space for residents and visitors to enjoy. This included improvements like wider sidewalks, green spaces, and artistic accents. 88% of the pedestrian area is shaded by tree canopy. 14% decrease in hardscape surface temperature. 276% increase in dedicated pedestrian area. 42% increase in existing tree growth area and organic soil. 300-ton carbon reduced from emission due to the use of 25% fly ash in the concrete mix. 38% increase in new sitting area and social gathering area, 100% use of native and adapted plants.33% of local stormwater is captured by rain gardens before draining. 75% bacteria removed, 73% phosphorus removed, 93% oil and gas remove, 85% of total suspended solid removed. The upgrades are 4 times increase night time light levels and so 30% reduce crime, 43 new bicycle rocks installed, 70 % increase in the use of bike cycling (Shearer, 2015).

2. METHODOLOGY

Methodology is an essential component that directs the entire process of conducting a study. A series of processes are generated in this investigation to facilitate the study's arrival at its ultimate destination. The methodology looks like:

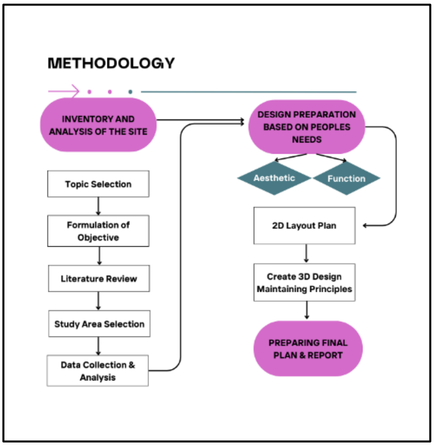


Figure 1. Flow Chart of Methodology (Authors' Preparation)

4. STUDY AREA PROFILE

4.1 Study Area Base Map

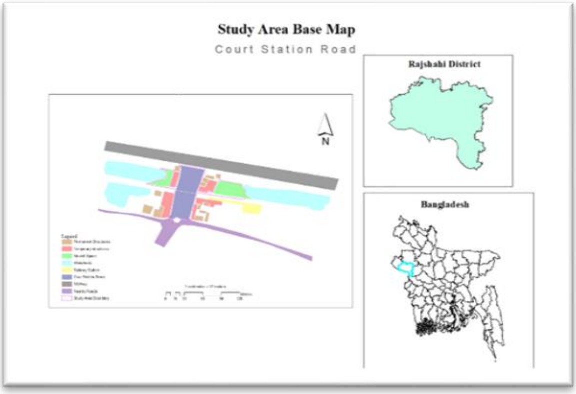


Figure 2. Study Area Base Map

4.2 Site Inventory

Site inventory plays an important role in landscape planning and designing. It helps to understand the current condition of the site and the available resources of the site that can be used during the landscape planning process. We went to the site for reconnaissance survey and started looking for some elements based on the literature review. The upmost priority was to understand the width of the road, available vegetation, the owner of the land, he occupancy of the land, drainage condition, foot path condition, the barriers, the waterbodies and adjacent railway station to understand the real time condition of the site. Condition of the Road: The road which we are concerned about is 325 feet (100 meters) in total. The road is equally divided in two portions with the railway line. The width of the road is 105 ft approximately. There are two speed bumps on the both side of the road for railway line. There were full of temporary vendors occupying the both side of the road. The two medians don’t divide the road equally. Also, there were a lot of auto rickshaw and motorbike parked on the road which was a mess.

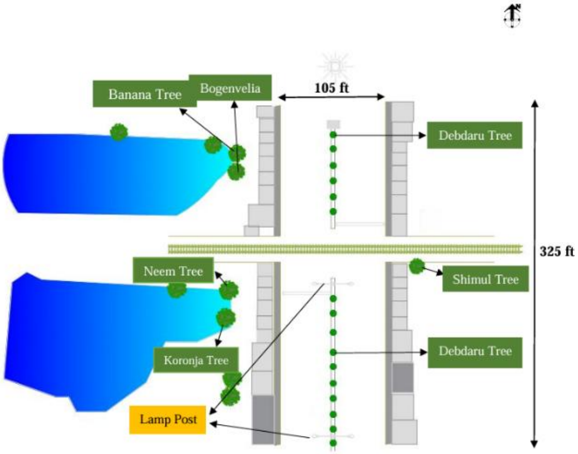


Figure 3. Condition of The Road

There are also some actual photographs can be shows which declares the condition of the site, which includes temporary vendors, photos at busy hours and less busy hours, photos during accident or parking problem and the actual image of occupied road width by vendors and parked vehicles.

Figure 4. Occupied By Vendors

Road have been occupied by parked bicycle, autorickshaw, motorbike etc.

Figure 5. Occupied by Vendors

A large number of vendors regularly come here and do business at the both side of the median. The total number of vendors as per our count was 18. Which can change on a weekly basis. And for occupying so much space, almost every day this place face minor accidents and clashes between easy bikes and autorickshaws. Also, bike accident is very regular here.

Figure 6. Minor Clashes Among Vehicles

There is some speed bumps put based on the accident frequency and vulnerability of the road. Also provides additional layer of protection from the rail line through the road

Figure 7. Speed Bumps on The Road

4.3 SWOT Analysis

There are some strengths, weakness, opportunities and threats of the site listed below at table 4:6.

Table 1. Swot Analysis of The Site

Strength	**Weakness**
Easily accessible road with more than 100 ft wide road Presence of light source Secured rail crossing	Temporary shops Traffic jam No Dustbin Little and improper vegetation Parking problems Footpath problem
Opportunities	**Threats**
Huge market place Business center Refreshment	Pollution Risky movement No zebra crossing

5. DESIGN PREPARATION

Design and descriptions play a crucial role in proposing the streetscaping project of Court Station Road, as they contribute to creating a more pedestrian friendly and engaging environment. The 2D and 3D designs of the suggested streetscaping project are included in this chapter, along with an explanation of the landscape's fundamental components.

5.1 Proposed 2D Layout

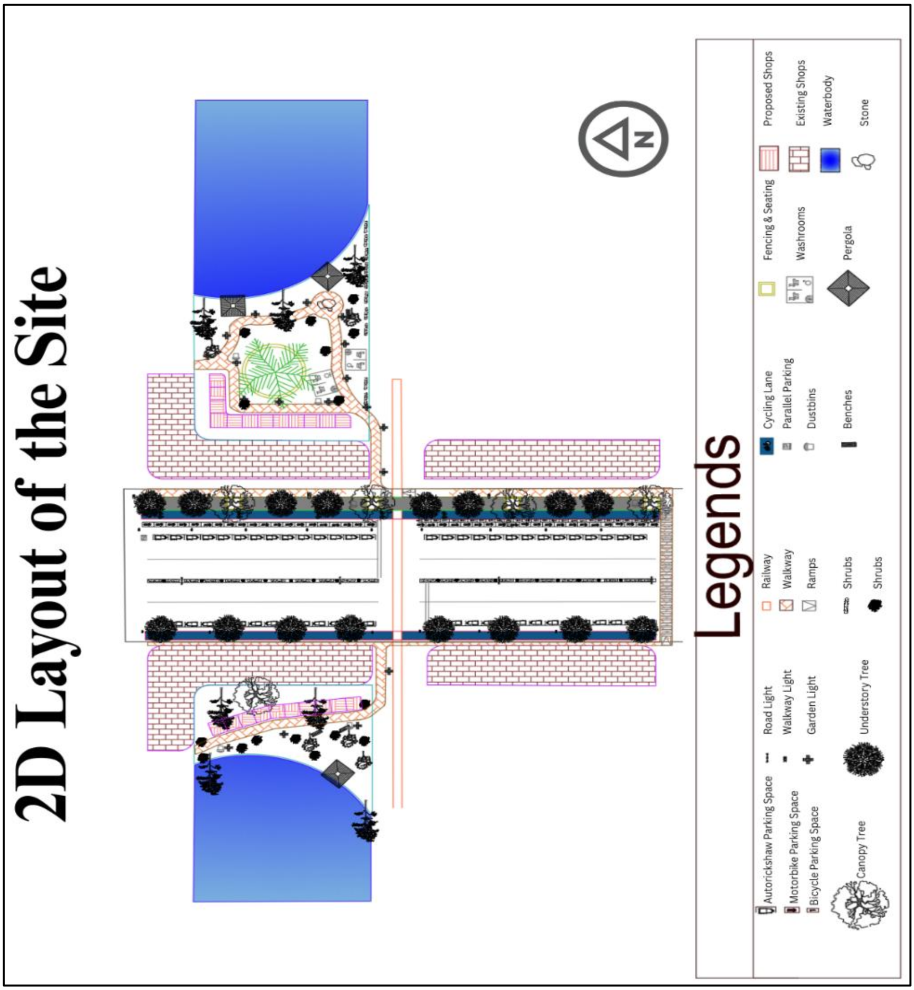


Figure 8. 2D layout of the site

5.2 Proposed 3D Design

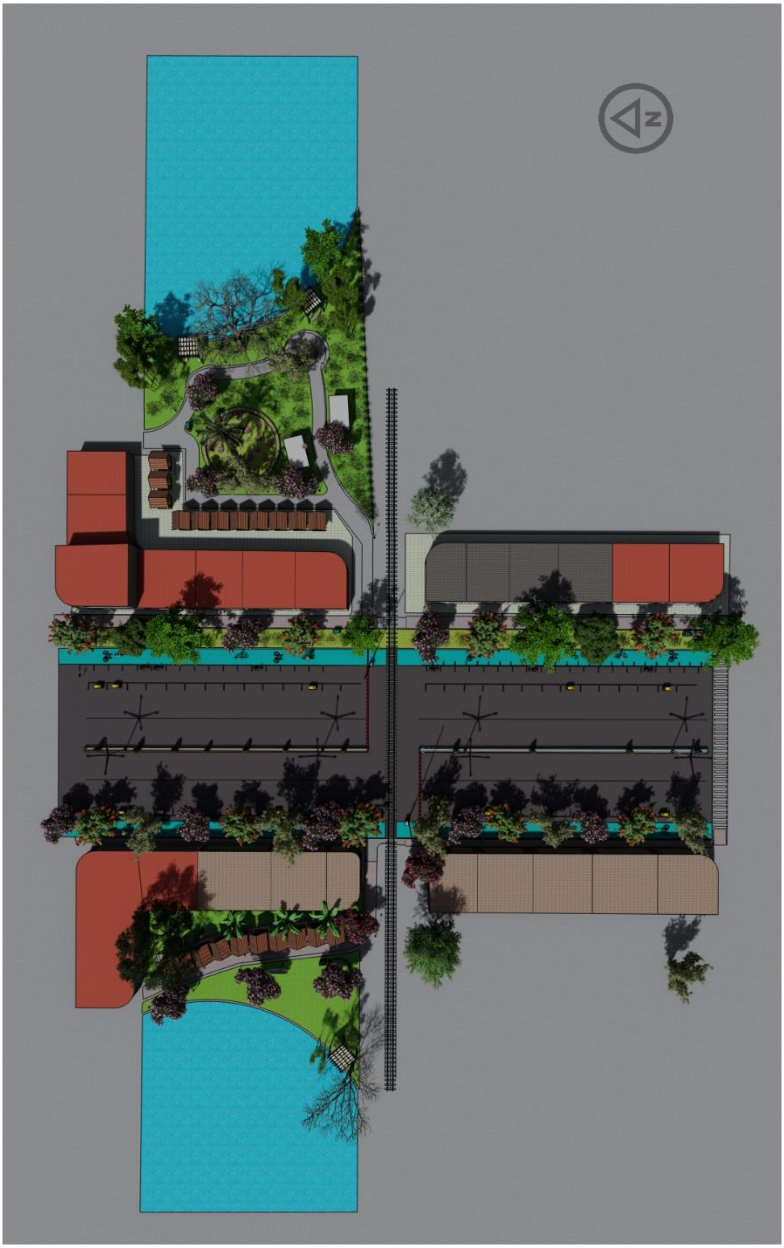


Figure 9. 3D Layout of The Site

5.3 Design Description

Walkability Enhancement

Walkway: To make a continuous and safe walkway the design considerations are very clear. In the figure 10 the walkway can be seen that it is level separated which is 4 inches up from the level on which vehicles run and has a width of 6.5 feet (for 1800). Based on the sensitivity of the road and proximity to vehicle the level gap can be varying from 4 inches to 6 inches (Sheefa, 2023). Because of a good distance (30 feet) from the vehicular movement we have decided to keep as low as possible.

Figure 10. Walkway Design Consideration

The material that has been used here is brick tiles. Since it is made of clay it can reduce surface heat more than 9 degree Celsius from asphalt. And there is also a great flexibility of changing the damaged bricks which is easy and too less costly. The texture surface of brick can help to keep better traction and the porous property of brick can help to reduce moisture.

Ramp: The ramp in figure 11 is here to ensure of access to the walkway and ensure continuity.

Figure 11. Ramp with Slope

The ramp has maintained a proper slopping which is 1:20 ratio of rise and run. The height of the ramp is 4 inches and the length of the ramp is 80 inches. The materials are same as the walkway to keep the property same.

Crosswalk: There was no crosswalk at the site. So, we have introduced a crosswalk for the ease of movement in a controlled manner (Figure 5:5). It can reduce the potential accident rate and ensure safety for walking. It is aligned with pedestrian desired walkway that is connected to ramp and continuous walkway. Using a single crosswalk was to ensure that the drivers don't get too much irritated while driving. A white color upon black asphalt creates a contrast that ensures high visibility in both during day and night.

Figure 12. Crosswalk to Control Movement

Cyclability Enhancement

Cycling Lane: The cycle lane ensures a segregated cycling path which is great for school going student and working people. The cycling lane has a width of 6.5 feet as well and it is also level separated and that has a sharp edge to prevent intervention. There was no specific provision for cycling and we did segregate the not motorized transport from the motorized transport. The cycling lane is distinct with markings, height and color. The green like color is for visibility (Figure 13). The materials are bio based polyurethane coating with a waterborne green acrylic paint on it that reduces the carbon footprint.

Figure 13. Cycling Lane

Green Buffer

Green Strip: The green strip is designed to actively reduce runoffs of storm water. There is also availability of stones to increase the infiltration rate. In figure 14 the width of this vegetation strip is 8 feet on the right side and 4 feet at left. This is to maintain minimum requirement to plant canopy trees as well as understory trees. Because the minimum opening required to plant such trees requires 16 square feet (Asaduzzaman & Sadat, 2020).So, the more width of green space will accommodate large trees and support infiltration as well.

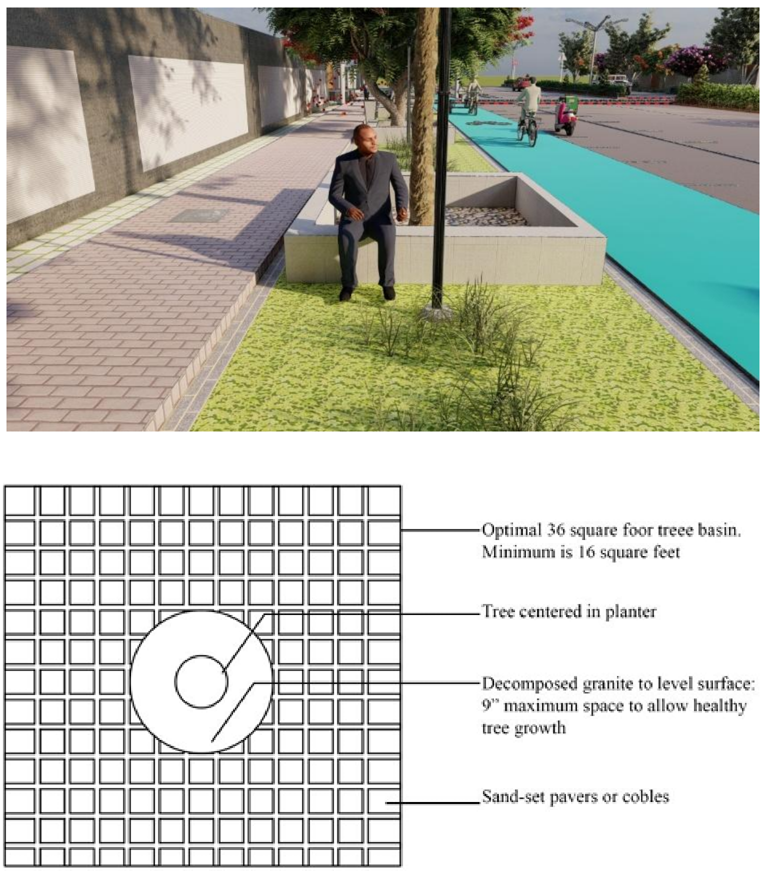


Figure 14. Vegetation Strip and Tree Basin

Figure 15. Fencing with Seating Functionality

Tree fencing: The tree fencing is primarily supposed to protect the trees and avoid interventions. The trees are mainly used for canopy shading and keep the surrounding cool. For proper growth and easy maintenance, a concrete fence has been used (Figure 15). Which also supports seating for on-the-go pedestrians. The building material high albedo concrete which is a mixture of zinc dioxide, titanium dioxide, silica gel, limestone and white sand. They have a good property of heat emission. The seating height is proportionate to human scale where height is 1.7 feet (*Accessibility Design Manual: 1-Urban Designs: 3-Street Furniture*, n.d.). Which means a matured man or woman can sit upon it without any problem.

Bypass Walkway and Social Spaces

Flower Bed: The flower bed is put there (Figure 16) to function as a transitional space. Flowers with various color range is available from cool white to warm yellow orange.

Figure 16. Flower Bed

A good range of flower can ensure a year wide blooming season and keep the place alive. There have been put flower shrubs like Petunia, Yellow Daisy, Zinnia, Chrysanthemum, Common Sage, Periwinkle, Lavender etc. Here (Table 5:1) the flowering season and other property are listed for better understanding of flowers and flowering season.

Table 2. Flower Details with Season

Local Name	**Scientific Name**	**Type**	**Height (ft)**	**Flowering Season**	**Image**
Petunia	*Petunia hybrida*	Herbaceous Annual	0.5-1.5	Winter to Spring (Nov-Mar)	
Yellow Daisy	*Tecoma stans*	Perennial Herb	6-10	Spring to Autumn (Mar-Oct)	
Zinnia	*Zinnia elegans*	Annual Herb	1-3	Summer to Autumn (Apr-Oct)	
Chrysanthemum	*Chrysanthemum morifolium*	Perennial Herb	1-3	Winter (Nov-Jan)	
Common Sage	*Salvia officinalis*	Evergreen Herb	1.5-2.5	Spring to Early Summer (Mar-Jun)	
Periwinkle	*Catharanthus roseus*	Evergreen Shrub	1-2	Year-round (Peak Apr-Oct)	
Lavender	*Azadirachta indica*	Evergreen Shrub	1.5-3	Spring to Summer (Mar-Jul)	

Relocated Shops: One of the key problems of the site was the vendors which were eating up the carriageway and space for walking. At the study and on ground observation we have found the number of temporary vendors was 18 and so with our design we have relocated them along with the bypass walkway. The shop standard that we have maintained for a kiosk of 100 square feet (Figure 17) (Heil, n.d.). Which is relatively large and will be able to fulfill their demand. Our design could accommodate a total of 24 vendors. The rest of the 6 has a potential future upgradability.

Figure 17. Relocated Shops

Boulder: The boulder creates a sense of curiosity which creates attraction and increase amount of footfall on the other side of the shops. There are things that can support the design consideration and enhances the acceptability of the design. The boulder is just a giant rock which is natural. This element can make the place photogenic and will also create something very opposite that is relevant to Rajshahi (Figure 18).

Figure 18. Placement of Boulder

Parking Strategies

Bicycle Parking: The bicycle parking provision has been kept for total 25 slots. Where the parking is maintained to be on parallel arrangement. Parallel parking is effective on on-street parking system. Because it doesn't demand for mode additional space. More space requirement increases the total cost for the project. The parking arrangement lies upon the cycling lane. The parking standard that we have maintained is 5.7'in length and 2' in width (Figure 19).

Figure 19. Bicycle Parking Spot

Motorbike Parking: The parking provision for motorbike is relatively more than the bicycle and there is provision for 40 motorbikes. The motorbike parking requires a space of 8 foot on length and 4 foot in width. The motorbike parking has a bike bay to get into and go out. The bay has a width of 6 feet (Figure 20). The parking provision for motorbike stands upon the asphalt of the road. The arrangement is also in parallel way. The parking provision is marked with while acrylic paint.

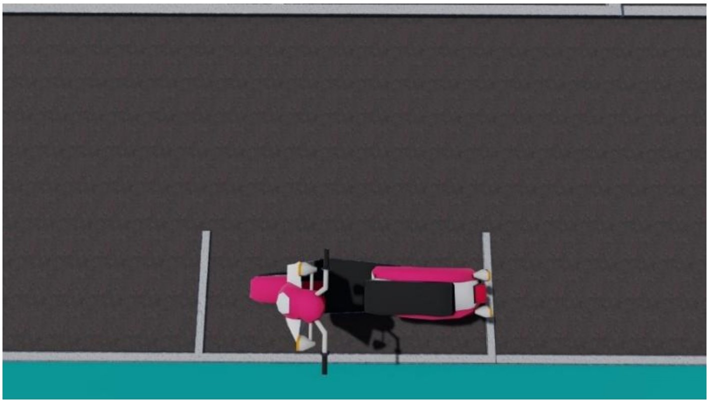


Figure 20. Motorbike Parking and Bike Bay

Autorickshaw Parking: From the traffic volume survey we get the greatest number of vehicular activities/ flows from autorickshaws and from figure 4:6, we can see a live collision between 2 autorickshaws which creates potential risk for the cyclist and pedestrians. For that reason, a large number of parking provision has been considered into our design in both directions to ease the movement on carriage way and a good enough space to stop for some time and call for passengers or drop them off. According to the dimensions of autorickshaws and calculated proportionate parking dimensions are 10 foot in length and 4 foot in width (Figure 21). We have considered parallel parking here also to avoid collision by keeping moving vehicle at blind spot. Number of autorickshaw parking spots is 56.

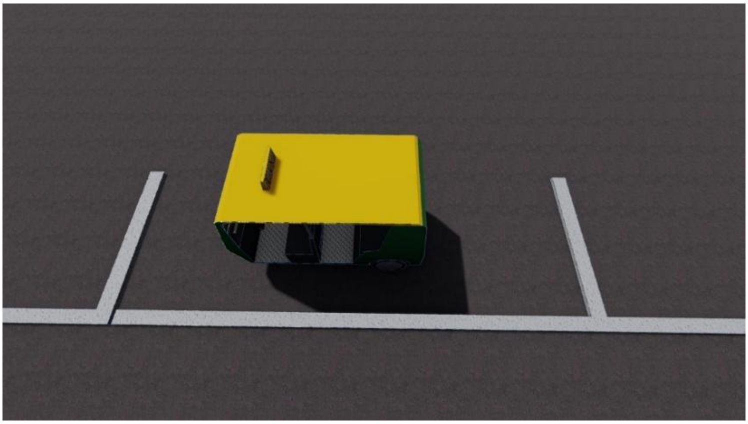


Figure 21. Autorickshaw Parallel Parking

Seasonal Tree Palate

Standard for Trees: Trees all over the road has been planted according the Pune municipality guideline for streetscaping(Pune Municipal Corporation, 2016.). We have considered two different patterns for tree plantation. We can see various pattern to be adopted according our need from (Figure 22). The second one which is one canopy and 2 understory trees on right side of the 3d layout in figure y and 4 understory trees at left of the street in per 100 linear feet.

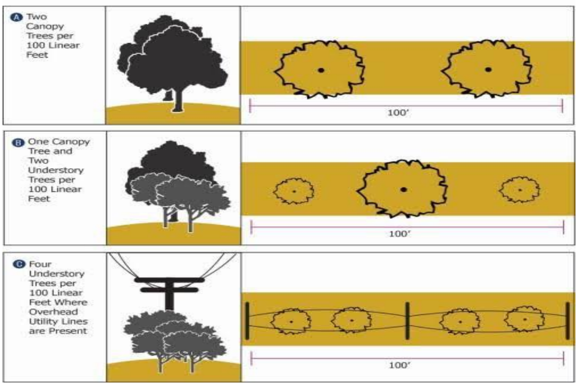


Figure 22. Tree Planting Standards for Streetscaping

Selection of Trees: Trees have been selected on multiple purpose. The purposes are, some trees need to exert fragrance, some other trees need to be focused on flower color and flowering season and some trees for create a soothing sound and obviously providing shade. Selected trees and their flowering seasonality are provided in table 3.

Table 3. Flowering Seasons and Color Variety

Common Name	Scientific Name	Type	Height (ft)	Summer	Rainy Season	Autumn	Late Autumn	Winter	Spring
Krisnachura	*Delonix regia*	Deciduous	30-40						
Shimul	*Bombax ceiba*	Deciduous	65-82						
Jarul	*Lagerstroemia speciosa*	Deciduous	45-65						
Chatim	*Alstonia scholaris*	Partly Deciduous	100						
Palash	*Butea monosperma*	Deciduous	33-40						
Shonajhuri	*Acacia auriculiformis*	Deciduous	40-80						
Neem	*Azadirachta indica*	Partly Deciduous	50-66						
Bagan Bilash	*Bougainvillea glabra/spectabilis*	Evergreen	3-16						
Debdaru	*Polyalthia longifolia*	Evergreen	40-66						

All the trees are capable of sustaining at weather condition of Rajshahi. Trees applicability has been selected from multiple sources. The sources are one (Asaduzzaman & Sadat, 2020.) and another on is from (Hasan, 2019.). All the trees were not proposed on this list. Some of them were available on site and some of them were proposed. The proposed trees are Shimul, Jarul, Chatim, Neem, Shonajhuri and Krisnachura. And the existing trees around the site are Polash, Debdaru and Baganbilash.

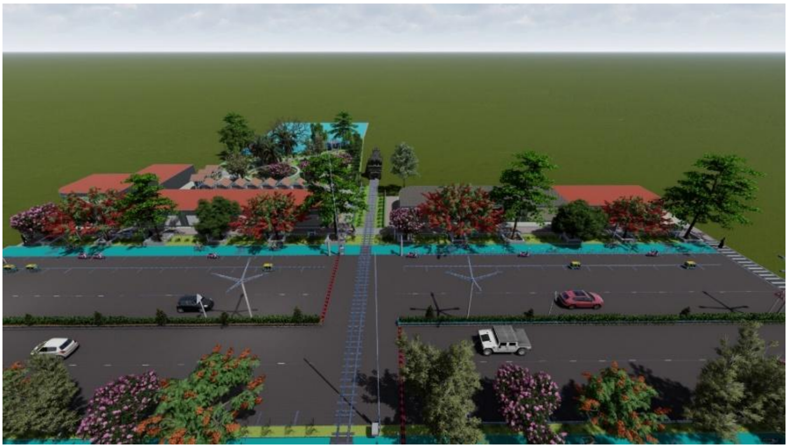
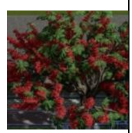
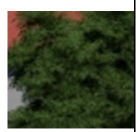


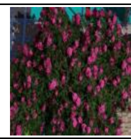
Figure 23. Variation of Trees.

Table 4. Rendered And Real Picture of Proposed Trees

Proposed trees	Shimul	Jarul	Chatim	Shonajhuri	Krisnachura	Neem
Rendered image						
Real image						

Here table 4 gives information about proposed trees and the table 5:2 provides picture of existing trees. All the trees provide a wide range of colors for the whole year. If you look table 5 carefully, you might find no single season in this flowering pattern and tree selection that have a downtime for the site. Which means trees provide shade almost all year long and trees provide flowers all year in a combined way. In this strategic way the site will never feel boring again. It will remain exciting whole year.

Table 5. Existing Trees

Existing trees	Polash	Debdaru	Baganbilash
Rendered image			
Real image			

Site Amenities

Dustbins: There are two types of dustbins have been provided side wide. The types of dustbins are for recyclable and non-recyclable wastes (Figure 5:17). The types of recyclable wastes relevant to our site are plastic bottle, newspaper, paper bag, food container, metals etc. Some non-recyclable wastes are used paper towels, plastic utensils, batteries, pesticides etc. The distance between one dustbin to another will be 100 feet by keeping the volume of footfall in such areas.

Figure 24. Dustbins For Recyclable and Non-Recyclable Wastes

Spittoons and Clean Water: The design is very summer friendly as directed. So, for free clean water and a spittoon has been placed to keep the people hydrated as well as keeping the site clean from spits of betel nuts and tobacco (Figure 25). There is only one spittoon has been designed to put on site to check its usability and acceptability. If there is a success, the number of spittoons can be increased to three.

Figure 25. Spittoon and Clean Water.

Inlets and Manholes: There are inlets on walkway to directly drain the storm water into underground drainage system to make a disturbance free and not slippery walking experience during monsoon. The distance between one inlet to another is 30 meters and a manhole is to keep the drainage clean between of the two inlets. Both of them are made of metals.

Figure 26. Inlets and Manhole on Walkway

5.3.8 Additional Safety Feature

Active Warning System: There lacks a barrier or warning system for the pedestrian and cyclists. So, we have incorporated an active warning system that includes and warns in different medium. We can see a warning sign in figure 27 of railway, there is also a hazard flasher on top of it to make that visible and to make it audible there is a warning bell that rings automatically when the train arrives and rail barrier drops on the road. So, this method does not create any visual hard barrier but it largely influences through both visionary and audible sensors.

Figure 27. Active Warning System

Bicycle Rack: A non-removable rack for every parked bicycle parked on the street is kept there to keep the bicycle locked and safe from thief. It also functions as a barrier to bicycle parking which saves space from encroachment by the motorbike parking nearby (Figure 28). The racks work as bollard as well. The color of rack is kept white and red to provide warning and alert. It also plays a role to become highly visible at both day and night.

Figure 28. Bicycle Rack for Safety

Fire Hydrant: This place is a semi commercial space with a numerous number of activities takes place. So, fire hydrant is an important inclusion for this site. The nearest fire station is approximately at 10-minute distance from this site. So, we have considered a fire hydrant which is single for 100-meter distance (Figure 29). Since our road is 100-meter-long we have included only one fire hydrant for the whole site.

Figure 29. Fire Hydrant for Safety

Steel Fence: On the both side of the rail track, there was a lack of safety protocols which was necessary. Fence is must have to this type of site. There have been put stainless steel fences on the both side of the railway track at the distance of maximum 8.5 foot or minimum 12 foot on the both side from the center (*Fencing Between Tracks at Stations | Federal Railroad Administration*, n.d.). The height of the fence should be kept 4.5 foot as it can vary from 1.2 meter to 2 meters.

Figure 30. Fencing By Railway Track

Usage of Signage

Designated Pedestrian Zone: There are two bypasses on the both side of the street has been created to optimize the street, redirect the rush and support relocated business exclusively for pedestrians. So, it is very necessary to put a designated pedestrian sign to allow pedestrian only. Cycling is also not recommended here (Figure 31). In this way, this place is safe for activities and relaxation for the pedestrians.

Figure 31. Designated Pedestrian Zone Signage

Cycling Lane Signage: A distinct and segregated movement of cycling can be ensured through use of signage. The signage means only cycling on this lane (Figure 32). There are also cycling marked on the pavement coating. In both side for each direction there is a signage put to ensure perfect flow of bicycles. This was necessary for the school going children who use cycle for daily travel.

Figure 32. Designated Cycling Lane

Crosswalk Signage: A signage for crosswalk and pedestrian circulation safety was put before the crosswalk (Figure 33). The vehicular speed in this street will be significantly low due to presence of speed bump. So, we have put a crosswalk signage 15 meters before the crosswalk or zebra crossing.

Figure 33. Crosswalk Signage

Parallel Parking Sign: To make a clear indication and management of parking provision for the site was selected as parallel parking. Parallel parking saves the carriageway and it also helps to avoid collision with the running vehicles to the parked vehicle (Figure 34). The quantity of parking signage is two located on both sides. The parking signage is on a blue plate which indicates an information type of signage.

Figure 34. Parallel Parking Signage

Speed Bump Signage: There are two existing speedbumps to reduce driving speed. But there was a lack of signage for speedbumps (Figure 35). In this design we have incorporated two signage for speedbumps on the site. It is located on median and approximately 30 meters ahead of the speedbumps to give driver enough time to reduce their vehicular speed.

Figure 35. Speedbump Signage

Site Detailing

Wind Breaker: The wind breaker is necessary for filtering out dust and extra bit of wind that comes from the movement of train. The wind breaker saves the seating space underneath the pergola a socializing place. So, to keep an uninterrupted socializing, the wind breaker helps very much to save the seated people from dust and sudden wind. In figure 36 we can see neem and Pabon Jhau is working together to reduce the effect of dust and extra bit of sudden wind. This type of setting for pergolas is available at both of the side of the site.

Figure 36. Windbreaker made with Neem and Pabon Jhau

Green Paving: Paving has been done with a strategy to increase the groundwater recharge through permeable paving (Figure 37). This type of paving has been installed under the relocated shops. It is expected to be clean and useful for infiltration.

Figure 37. Green Paving Under Shops

Night View

The night life at the site is perfectly balanced as the day light. The design consideration for the overall site introduces safety and secured movement of pedestrians. Lighting for the site ensures safety that is required. This is to encourage people for the activities and ensure maximum footfall.

Figure 38. Lighting Ensures Continuous Visibility

Lights have been strategically selected for high flux to complement the both action of walking and cycling (Figure 38). High lumen lights ensure safety and action. The lights maintain a perfect distance to height ratio that can be maintained here. To maintain proportion of human scale the height of the lampposts is 3 meters and the distance from one lamppost to another can vary from 2.5 times to 3 times of the height. In our case we have used a 25 feet distance which equivalent to 2.5 times of 3 meter to ensure continuous visibility on walkway and bicycle lane.

Figure 39. Improved Lighting on Carriageway

The illumination over the carriage way which is 30 feet for two lanes has been ensured with a 30 feet tall lamp post. The distance from one lamp post to another is to be maintained through multiplying the height by 2.5 or three. The lampposts height gives a proper lumen radius to the both walkways, cycling lane and carriageway.

Figure 40. Lighting at Entrance of Designated Pedestrian Zone

To ensure soft and spot lighting for transition from hardscape to softscape a soft spot lighting has been used (Figure 40). It directs human eyes to the flowerbed under it. It can be seen that flowers are looking beautiful at night also from here. These soft ambient lights are encouraging for the people who want to have some time for relax. With these lights a soft night environment can be created here. The flower foliage can be seen perfectly due to the perfect lighting condition. The seating place with a round edge with no direct lamppost directed on it ensures a relaxed space for seating here at figure 5:34. The rounded seating space is to guide the human eye to the flower bed available here. Also, a sense of relaxation can be found here with two strategic light poles partially covering the seating space. It also adds a depth of field with lights and shadow play.

Figure 41. Rounded Seating with A Depth of Lighting

The flowerbed is a relatively large rounded space but the small spot lights add more details and makes a perfect balance to it. The lights are small that goes with the unity of small flowers of the garden (Figure 42). The lights are also used to guide human eye through the rounded wall from inside and show a maximum variety of flowers on the flower bed.

Figure 42. Spotlights on The Flowerbed

The pergolas with seating arrangement need also the warmth of lights. It is necessary to provide a dedicated lighting solution to the pergola each to ensure maximum safety. But the lights cannot be emitting too much flux from it. A gentle soft and warm lighting condition to be provided which can create a shadow play with the light and pergola (Figure 43). So, the height of the light must be high from the pergola.

Overall, a perfect lighting condition has been incorporated to properly illuminate the site from the walkaway to the toilets to the other seating spaces. The lights are perfect for a gentle movement of pedestrian and a welcoming environment.

Figure 43. Light and Shadow on Pergola

5.4 Inclusion of Elements and Principles of Landscape Planning

5.4.1 Color

In this streetscaping study we have introduced multiple color scheme to the site and they are monochromatic and polychromatic color scheme. There is a use case of warm color and cool color as complementary scheme. All these color schemes are used strategically to relax or promote action or transition. There is also a repetition of colored flowering shrubs and trees to create unity and rhythm. Usage of color can be varying their function into different setting of the surrounding environment.

Monochromatic Color Scheme: At the entrance of the designated pedestrian zones in both sides there have been used a monochromatic color scheme to directly compliment the hardscape of the road. The monochrome is from color blue. We can see in figure 44 the color has been shifting from white blue to blue to purple. Which is perfect example of monochromatic color scheme. The monochromatic blue encourages relaxation and calmness which was actually the intention of ours while designing.

Figure 44. Blue Monochrome Color

Polychromatic Color Scheme: While designing the whole site, we have used polychromatic color scheme. Polychromatic color scheme includes red, green, blue, oranges, purple, pink, white etc. at once. We can see them in table 5:1. In figure 45, we can see a variety and range of flower color within the flower bed at once. It expresses a season change and rhythmic color flow.

This sort of arrangement can promote energy and playfulness. And most importantly this creates a focal point that attracts everyone.

Figure 45. Glimpse Of Polychromatic Color Scheme

Complementary Color Scheme: The mixture of warm color and cool color produces a complementary color scheme in our study design. The placement of cool Jarul flower with contrast to Black Eyed Susan (Yellow Daisy) creates a sense of complementary color scheme in figure 46. It creates a depth of movement. Due to strategic positioning of complementary color scheme by the walkway creates a depth and supports movement at static places (pergola and rounded seating arrangement). It also creates a balance.

Figure 46. Complementary Color for Warm and Cool Colors

5.4.2 Forms

In landscaping design, form refers to the shape that can be in regular geometric order or organic edges. In our design we have incorporated both geometric design and irregular or organic edges. There has been using regular rectangular shape of Pabon Jhau or boxwood can also be used to provide restriction and work as a wall (Figure 47). The wall is required to keep the study area separated and safe from railway track.

Figure 47. Used Square Forms

The usage of natural boulder with organic edges enhances the sense of natural environment that is completely mind refreshing at the side of the metaled surface of the road. The boulder also creates a sense of curiosity in figure 5:12. We have used a set of rock to make a path more interesting. The interesting path can lead to the circular seating space which cannot be ignored by visitors (Figure 47). So, to enjoy the nature, one must experience walking on the rocks.

Figure 48. Irregular Edges of Rock

5.4.3 Line of Sight

Straight line and meandering line have been used here to walkway on different setting. The walkway with parallel to the road is used here to direct people and encourage a forceful walk at the walkway. It also creates a symmetrical design parallel to the hardscape (Figure 49).

Figure 49. Straight Line Parallel to Road

There is also usage of meandering line with respect to the bypass greener space. Meandering line is more informal and it supports activity around it (Figure 50). It is not forceful. Its rather inviting than forcing movement encourages to meander around and enjoy the nature. It's often relaxing with the surrounding environment.

Figure 50. Meandering Line on Walkway

5.4.4 Scale

The scale refers to the dimensional relationship between one landscaping element to other landscaping element. The scale is kept low at seating spaces and pergolas. Generally low scale elements blend together and it also promotes relaxing and calmness. People can spend much more time into this setting. The pergola with adjacent bamboo trees creates a perfect scale for sitting there inside pergola.

Figure 51. Relationship of Scale Between Pergola and Bamboo Tree

The two lines in figure 5:44, yellow (Bamboo) and red (pergola) shows height and the comparative relationship between two of them. And as a result, people enjoy sitting there and have some snacks and spend more time there.

5.4.5 Texture

Texture is the quality and type of surface that can be looked or feel about. The look and feel may vary from one element to another. There are textures like coarse, fine or medium. Texture can create contrast and increase the interest.

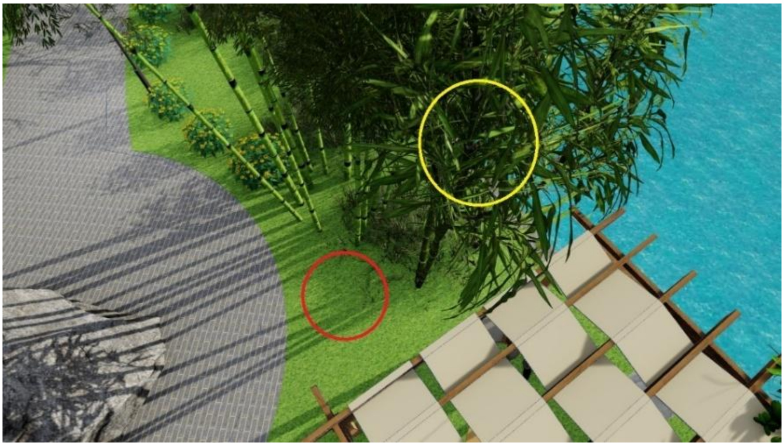


Figure 52. Fine and Coarse Texture

The yellow circle in figure represents a coarse texture from bamboo leaves and the red circle represents fine textures from grass (Figure 5:45). They overall create a contrast and add more interest to this place.

5.4.6 Unity

In this design of outdoor landscaping, we brought unity through a continuous use of color palette. All the adjacent colors are available here from color palate which creates a central theme for the landscaping project (Figure 53).

Figure 53. Unity With Color Palate

5.4.7 Balance

The distribution of mass according the equity and mass creates balance. Here the use of balance has a perfect example in our design. In figure 54, on left we can see large canopy trees and a few numbers of trees comparing to the right side which has more but smaller trees. But the distribution of trees has been considered upon the road ratio of road width on both side of the median. At left the road is much wider than left.

Figure 54. Asymmetrical Balance Achieved by Number and Height of Trees

5.4.8 Proportion

Proportion refers to design something by keeping in mind the human scale. Proportion can be used to determine heights of seating space, or height of any structure or even it can be used to determine the tree foliage and trunk height. In figure 55 the tree leaves are in comfortable height from human height that doesn't outpace the human and also doesn't create any sort of disturbance.

Figure 55. Proportion of Trees

5.4.9 Transition

Transition helps to introduce a change of environment in a smoother way. In our design there is a transition from hardscape to softscape. This transition was done on both sides by the help of flowers and gradual change of color (Figure 56). The color scheme was chosen monochromatic and of cool tone. This feature creates a seamless experience and helps to adopt better with places.

Figure 56. Transition from Hardscape to Softscape

5.4.10 Rhythm

Rhythm can be used to pace up or pace down the movement and direct viewers eyes. Our design incorporated rhythm to show the change of vehicle speed after sometimes. The speed here is controlled with speedbumps, crosswalks and intersections. The rhythm was achieved by variation of tree and their heights (Figure 57).

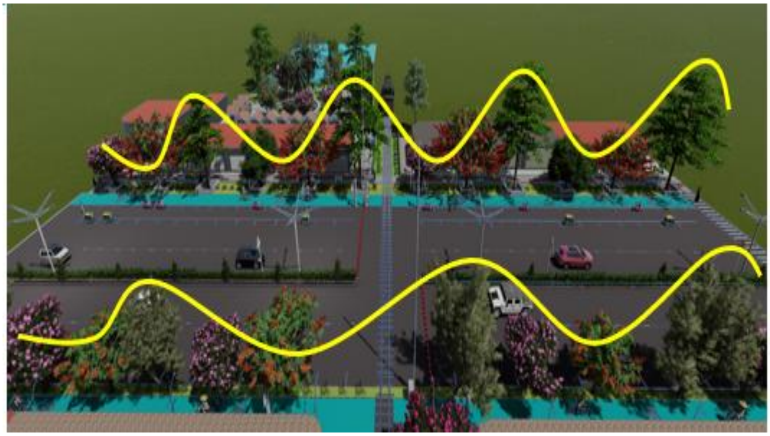


Figure 57. Rhythm with Tree Heights

5.4.11 Focalization

Focal points are important to attract people to engage into some secondary activity. In our design there is a huge rounded seating arrangement with polychromatic color scheme (Figure 58) that stands out from the whole site and some shops around it can make better use of it. There is also usage of boulder that will be another focal point to create attraction over the pergolas behind it (Figure 58).

Figure 58. Focalization with Shape and Color

5.4.12 Repetition

To create harmony and flow we have placed same trees after certain distance to create repetition (Figure 59).

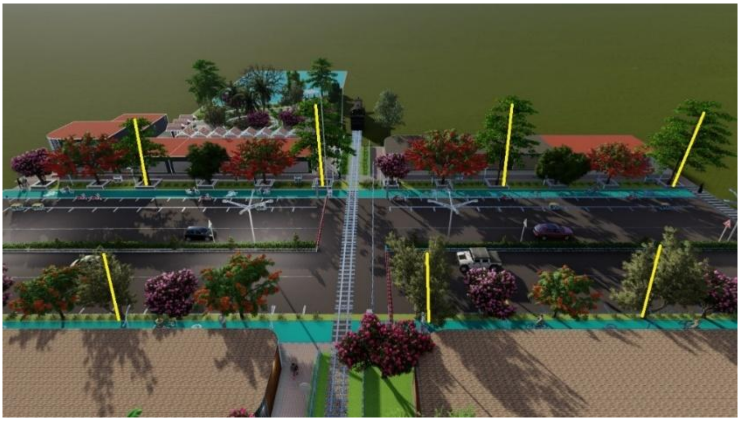


Figure 59. Repetition of Trees

CONCLUSION

This study provides an insight about how a visionary and sustainable transformation can be done through planning and designing. The road is currently facing so many problems and to make the perfect use of this road and ensure pedestrian and cycling safety the road is designed. There is usage of unused government spaces that can help to level up the design.

It promotes a design that makes transition from vehicle domination to human centered and scaled design. The transition from busy road to livable, inclusive and vibrant urban bypass for walkways. It reduces complexity and promotes social interaction, leaves the fear of accident and collision behind which truly reflects the title “A Street for Tomorrow”. This project can set a replicable standard for the whole city where schools, colleges are available in high volume. This project is a rework of social interaction where people walk, gather and interact together. The plan of this project reflects the necessity of Rajshahi people and incorporation of design according them. Solves issues of heat island, potential threats of accident and security. Implementation of this project will work as a symbol of modern urbanism which reduces carbon footprint.

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CHAPTER 3
LONG TIME HYDRAULIC CONDUCTIVITY OF ELECTROKINETIC REMEDIATED LEAD CONTAMINATED SOIL

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INTRODUCTION

Soil contamination is a critical global environmental challenge, with Nigeria experiencing increasing impacts from industrial activities, agricultural practices, mining operations, accidental spills, and improper disposal of hazardous waste [citations needed]. These contamination sources adversely affect ecosystems and human health through soil degradation, groundwater pollution, and deterioration of drinking water quality [citations needed].

Among various solid waste management strategies—including recycling, composting, and incineration—landfilling remains the predominant method for municipal solid waste (MSW) disposal, particularly in developing nations [citations needed]. Engineered landfills comprise three critical components: impermeable liners, protective covers, and leachate collection systems, all designed to prevent contamination of surrounding soil, water, and air while minimizing risks to public health and the environment [citations needed].

Traditional performance criteria for hydraulic barriers in waste disposal facilities include: (i) minimal hydraulic conductivity ($k \leq 1 \times 10^{-9}$ m/s), (ii) adequate shear strength, and (iii) minimal susceptibility to desiccation cracking and volumetric shrinkage (Moses et al., 2013; Rowe et al., 1995; Daniel & Benson, 1990). Additionally, chemical compatibility between the liner material and permeating leachate is fundamental, as incompatibility can cause significant variations in hydraulic conductivity (Shackelford et al., 2000).

Common liner materials include natural clay, geomembranes, geosynthetic clay liners (GCLs), and compacted soil. Clay is favored for its low permeability and contaminant attenuation capacity [citations needed]. However, synthetic materials such as geomembranes and geosynthetics, while offering puncture resistance and reinforcement, have limited application in developing countries due to high costs, installation complexity, susceptibility to failure, and lack of contaminant attenuation properties (Regadío et al., 2020; Kaza et al., 2018). Nigeria possesses abundant lateritic soil deposits that remain underutilized as liner materials. While extensive research has focused on clay-based liners, limited studies have examined lateritic soil for hydraulic barrier applications, despite its successful use in embankment dams and highway construction [citations needed].

Furthermore, the potential for remediating contaminated lateritic soils for reuse in environmental applications remains largely unexplored. This study investigates the long-term hydraulic performance of electrokinetically remediated lead-contaminated lateritic soil as a liner material for MSW containment facilities. Specific objectives include: assessing the compatibility of remediated soil with water and MSW leachate, evaluating changes in hydraulic conductivity over a 90-day permeation period, characterizing microstructural changes using scanning electron microscopy (SEM) and determining optimal lead contamination levels for effective remediation and reuse

1. MATERIALS AND METHODS

This study involves the usage of many materials all of which were used in different laboratory experiment in order to investigate the suitability of electrokinetic remediated lead contaminated lateritic soil for use as liner in landfill.

Lateritic soil: The soil used in this research was obtained at 1.5 m to 2.0 m by the method of disturbed sampling from a lateritic soil formation situated at Shika in Zaria, Kaduna State (latitude 11°15'N and longitude 7°45'E).

Leachate: The leachate from municipal solid waste (MSW) from a depressed, exposed area of an active open landfill site located close to the primary school of the Local Government Authority (LEA) in Samaru, Zaira, Nigeria was used. Table 1 presents the chemical properties of the municipal solid waste (MSW) leachate used in the study.

Lead nitrate: Lead nitrate salt obtained from Guanghua Sci-Tech Co., Ltd

Table 1. Chemical Characteristics of Municipal Solid Waste Leachate Samples Used.

Parameter	Leachate A	Maximum Permitted Limit
pH	9.60	6.50-8.50
Odour		Unobjectionable
Colour (TCU)	138.00	15
Taste		Unobjectionable
Temperature (°C)	28.10	Ambient
Turbidity (NTU)	226.00	5.00
Conductivity (mS/cm)	3.15	0.15-0.30

Total Dissolved Solids (mg/l)	1451.00	500.00
Total Hardness (mg/l)	183.00	150.00
Chloride (mg/l)	138.00	<4.00
Iron (mg/l)	7.02	0.30
Lead (mg/l)	2.11	0.01
Nitrate (mg/l)	133.00	45.00
Sulphate (mg/l)	111.00	<10.00
Sodium (mg/l)	27.60	<3.00
Zinc (mg/l)	5.30	0.00
Chromium (μg/I)	135.00	0.00
Calcium (mg/l)	244.00	75.00
Potassium (mg/l)	121.00	55.00
Magnesium (mg/l)	2.60	20.00
Manganese (μg/I)	20.14	0.20
Dissolved oxygen (mg/l)	1.35	6.00
Biological Oxygen Demand (mg/l)	23.43	3.00
Chemical Oxygen Demand (mg/l)	1386.00	<20.00

2.1 Preparation of Sample

The sample preparation involved inducing soil contamination with lead ions at various concentrations: 0%, 0.2%, 0.4%, 0.6%, 0.8%, and 1% by dry weight of the soil. These concentrations correspond to 2000 mg/kg, 4000 mg/kg, 6000 mg/kg, 8000 mg/kg, and 10,000 mg/kg, as reported by Udiba et al. (2020) and Tirima et al. (2021).

Artificial Contamination of Soil Samples

A total weight of 117 kg was distributed evenly among five distinct plastic containers, with each container being filled with soil. The soil sample contained in each bucket was meticulously blended with lead nitrate salt in incremental steps of 0.2%, ranging from 0% to 1%, relative to the dry unit weight of the sample. The combination was allowed to undergo a period of one month in the laboratory, in line with the findings of Resmi et al. (2011) and Karkush et al. (2013), in order to attain a uniform saturation of lead nitrate. According to Gang et al. (2021), following a period of 30 days, the soil that had been contaminated was subjected to a 10-minute stirring process in a mixer. This was done with the intention of achieving a uniform and sufficient dispersion of lead nitrate throughout the soil.

Subsequently, the soil was subjected to air-drying in trays under ambient conditions, followed by pulverization. The resulting soil particles were then carefully collected and kept in polyethylene bags subsequent to their passage through a 2 mm sieve.

Soil Sample Preparation for Electrokinetic Remediation

About 15 kg of the contaminated soil, worked up to water content about its liquid limit was compacted each into three electrokinetic cells set up with graphite electrodes at both terminals. Agreeing with Yeung et al. (2015), a direct current (DC) power source was applied to run a voltage of 30 volts across the electrodes in order to attain a voltage gradient of 1V/cm. The anolyte and catholyte solutions were both prepared with a concentration of 0.1 M acetic acid. Following the completion of the test, the soil sample was partitioned into five equivalent portions. The soil samples were meticulously excavated using a spatula, and each section extending from the cathode to the anode was systematically designated as S1-S5. Subsequently, the soil was subjected to a drying process in preparation for testing.

2.2 Laboratory Tests

Index Properties

Laboratory experiments were carried out to ascertain the index properties of the natural soil and the soil treated with electrokinetic technique, following the guidelines outlined in British Standards BS 1377 (1990) and BS 1924 (1990) correspondingly.

Hydraulic Conductivity

The hydraulic conductivity was determined using the rigid wall permeameter under falling head conditions, following the recommended method by Head (1992). A relatively short sample was connected to a standpipe to establish the water head flowing through the sample. The specimens were compacted using the BSH compaction effort. The natural and electrokinetic lead remediated soil samples were molded at water contents that were 2% higher than the optimum moisture content (OMC). To ensure full saturation, the specimens were soaked in a water tank for a minimum of 24 hours.

Measures were taken to prevent vertical swelling of the samples during saturation. After saturation, the six samples were permeated with water under falling head conditions for 90 days. It was first permeated with tap water for 21 days to obtain full saturation, and then with MSW leachate for the remaining 69 days during this process, the test specimens were allowed to swell vertically without the application of any vertical stress. Using equation (1), the coefficient of permeability (k) in m/s was calculated.

$$k = 2.303 \frac{al}{100At} log\left(\frac{h_1}{h_2}\right) \tag{1}$$

where: a = Cross-sectional area of the standpipe (m^2).

L = Length of the specimen (m).

A = Cross-sectional Area of the soil sample (m^2).

h_1 and h_2 = Initial and final heights of water levels in the standpipe (m).

t = Time in seconds

k = Coefficient of permeability (m/s)

Scanning Electron Microscopy (SEM)

The Scanning Electron Microscopy (SEM) analysis is a crucial technique used to investigate the microstructural and compositional changes in the lateritic soil samples before and after remediation and hydraulic testing. This analysis is vital for understanding the underlying mechanisms that govern the observed macroscopic changes in hydraulic conductivity. The test was conducted using a Phenom-World Pro desktop SEM. This specific type of desktop SEM is known for bridging the gap between traditional optical microscopy and high-end floor-model SEMs, offering high-resolution imaging and integrated analytical capabilities in a user-friendly format. The use of a desktop SEM suggests a focus on quick, reliable, and routine microstructural characterization.

Integrated Analytical Capabilities

The Phenom-World Pro desktop SEM is equipped with an advanced software application that automates data collection and image interpretation, allowing for a comprehensive analysis beyond simple surface imaging. The key analytical functions utilized for the lateritic soil study include:

Microstructural Analysis (Imaging)

The SEM uses a focused beam of electrons to scan the sample surface, and detectors capture various signals (primarily secondary and backscattered electrons) to produce high-resolution images. This provides qualitative information on the soil fabric:

Surface Texture and Topography: Visualizing the shape, size, and arrangement of individual soil particles and aggregates.

Pore Structure: Examining the size and distribution of inter-aggregate and intra-aggregate pore spaces, which are directly related to the soil's permeability.

Bond Formation: Identifying new cementitious products (if any) or flocculation of soil particles resulting from the electrokinetic remediation and interaction with lead or leachate.

Elemental Identification (Automated Image Mapping)

This capability is often provided by an Energy Dispersive X-ray Spectroscopy (EDS/EDX) detector integrated into the SEM. When the electron beam strikes the sample, it causes the emission of characteristic X-rays, whose energy is unique to each element.

- Elemental Composition: It allows for the identification of major, minor, and trace elements present in the lateritic soil (e.g., iron, aluminum, silicon) and, critically, the lead (Pb) contaminant.
- Automated Image Mapping (Elemental Mapping): The software automatically maps the spatial distribution of these elements across the scanned area. This is essential for visualizing:

The initial location and concentration of the lead contaminant.

The effectiveness of the electrokinetic remediation by showing the reduction or redistribution of lead across the soil particles.

Changes in the chemical composition of the particle surfaces after exposure to leachate.

Fiber-metric Analysis

While more commonly used for analyzing materials like filters or composites, the Fiber-metric software application can be adapted to quantify elongated structures within the soil samples, such as:

- Needle-like formations: Quantifying the size and orientation of any newly formed crystalline structures (e.g., hydrated phases) or elongated clay minerals.
- Morphological Quantitation: Providing objective, statistical data on particle shapes and connectivity, which impacts the overall soil fabric and its ability to resist fluid flow.

3D Roughness Reconstruction

This is a powerful feature, often employing a technique like 'shape from shading' using a segmented Backscattered Electron Detector (BSD).

- Surface Quantification: It allows for the generation of a three-dimensional (3D) topographical map of the sample surface.
- Roughness Measurement: The software calculates quantitative roughness parameters (e.g., R_a (average roughness) and R_z (roughness height)) at the sub-micrometer level.
- Structural Impact: For lateritic soil, analyzing the 3D roughness can reveal how the electrokinetic process and subsequent compaction modify the micro-texture of the soil particles, which ultimately influences the interlocking and overall structural stability of the compacted liner material. A denser, more homogeneous, and less porous structure is expected to correlate with the desired low hydraulic conductivity.

3. RESULTS AND DISCUSSION

The results of all the laboratory tests carried out on the lead contaminated and electrokinetic remediated soils are presented and discussed below.

Table 2. Index Properties of Natural Soil and Electrokinetic Remediated Soil

Engineering Properties	Natural Soil. 0%	0.2% EKR	0.4% EKR	0.6% EKR	0.8% EKR	1.0 EKR
Natural moisture	22.70	---	---	---	---	---
content	52.00	49.40	48.00	47.60	47.00	39.60
Liquid Limit, %	22.93	22.01	29.02	29.49	29.24	22.01
Plastic Limit, %	29.07	27.39	18.92	18.12	17.76	17.59
Plasticity Index, %	12.14	11.43	10.00	9.00	7.60	5.00
Linear Shrinkage, %						
Percentage Passing	82.15	7.68	8.50	9.75	4.60	5.85
BS No. 200 Sieve.						
(BSL)	82.15	5.09	9.78	9.06	10.30	5.50
Percentage Passing						
BS No. 200 Sieve.	82.15	10.4	14.8	7.73	10.30	5.60
(WAS)	A-7-6	A-7-6	A-2-6	A-2-6	A-7-6	A-7-6
Percentage Passing	CH	CL	CL	CL	CL	CL
BS No. 200 Sieve.	2.67	2.63	2.54	2.58	2.43	2.39
(BSH)						
AASHTO	1.68	1.78	1.78	1.79	1.74	1.86
Classification	1.76	1.87	1.84	1.61	1.86	1.86
USCS Classification	1.84	1.96	1.97	1.97	1.96	1.94
Specific Gravity						
MDD mg/m^3	19.00	13.20	14.40	14.60	14.98	15.60
Standard Proctor	16.80	13.10	13.40	13.00	11.20	13.40
West African	14.00	10.40	9.40	10.60	10.80	11.66
Standard	4.20	5.83	6.0	7.03	5.6	4.28
Modified Proctor	Brown					
OMC%	Muscovite					
Standard Proctor						
West African						
Standard						
Modified Proctor						
pH Value						
Colour						
Dominant Clay						
mineral						

Daniel (2012) and Benson et al. (1994) have proposed that a liner material should contain 20–30% fine particles. The results in Table 2 contains the appropriate proportion of fines and sand fraction for achieving a hydraulic conductivity of less than 1.9×10^{-9} m/s.

Benson et al. (1994) specifications for compacted soil liners are LL>20% and PI >7%, and all the electrokinetic remediated lead-contaminated soil met the LL and PI design requirements (Table 2) The liquid limit varied from 50.29 – 48.69 %, while the plastic limit ranged from 35.1 – 27.92% resulting in an increase of plasticity index (PI) values from 15.19% to 20.77%. Cation exchange and flocculation/agglomeration are the major reactions responsible for alterations in texture and plasticity. The structure of the modified soil mixture contains bigger particle agglomerates that are more friable and workable.

3.1 Effect of Municipal Solid Waste Leachate on Long-Term Hydraulic Conductivity

The variations of hydraulic conductivity with time for 0, 0.2, 0.4, 0.6, 0.8, and 1.0 % of electrokinetic lead remediated soil permeated with water and leachate is shown in Figure 1:

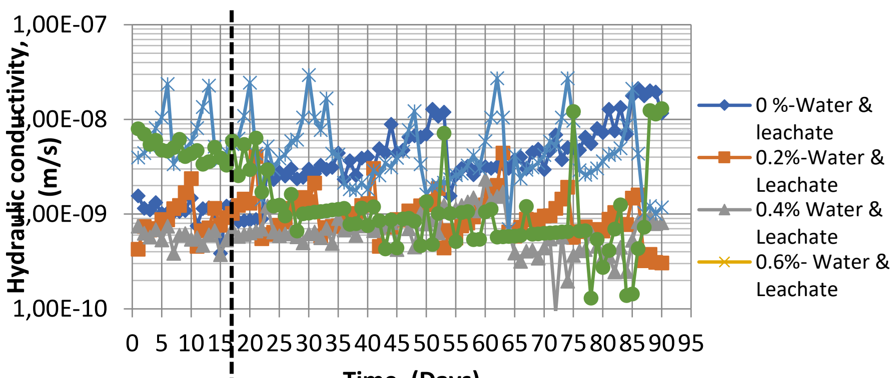

Figure 1. Variation of Hydraulic Conductivity with Time (Different Lead Concentrations) for 90 Days

The appearances of the top of the specimens after permeation by water and leachate are shown in Plates 1-6 respectively. The baseline hydraulic conductivity for the uncontaminated soil specimen before the permeant was changed from tap water to MSW leachate was 1.57 x 10^{-9}m/s, while the value at the end of permeation with leachate was 7 x10^{-9} m/s thus indicating an increase by a factor of 5.43.

For the specimens 0.4%. 0.6%, 0.8%, and 1.0% the baseline hydraulic conductivity values were 7.50 x 10 $^{-10}$ m/s, 5.91 x 10^{-9} m/s, 3.96 x10^{-9} m/s, and 8 x 10^{-9} m/s that decreased to 5.31 x10 $^{-10}$ m/s, 5.7 x 10^{-9} m/s, 1.03 x 10 $^{-9}$ m/s, and 4.35 x 10^{-10} m/s by factors of 2.19, 0.21, 2.88, and 3.65.

Plate 1: 0% electrokinetic lead remediated soil.

Plate 2: 0.2% electrokinetic lead remediated soil

Plate 3: 0.4% electrokinetic lead remediated soil.

Plate 4: 0.6% electrokinetic lead remediated soil

Plate 5: 0.8% electrokinetic lead remediated soil.

Plate 6: 1.0% electrokinetic lead remediated soil

Figure 2. Electrokinetic Lead-Remediated Soil Specimens

The trend recorded is similar to the gradual decrease in hydraulic conductivity reported by other researchers (Ozcoban et al., 2013; Petrov and Rowe 1997; Shackelford et al. 2000; Egloffstein 2001; Amadi, 2008; Moses, 2012; Oluremi, 2015; Osim 2017). For 0.2% increase from 4.26 x 10^{-10} m/s to 7.79 x 10^{-10} m/s with an increase factor of 5.33. At the end of permeation, dark slimy residuals were observed on the specimens as shown in Plate 1-6. The observed changes in hydraulic conductivity could be due chemical clogging (mineral precipitation) during the electrokinetic processes that involve (electro migration, electro-osmosis, and electrophoresis) which lead to the increment in the existing element of formation of new elements as shown in plate 2 to 6 which is in line with the work of Amiralian et al. (2012) where conductivity decreases with increase in lime and fly ash and also Taipodia et al., (2011) where the hydraulic conductivity also decrease as a result of nano CaO to the clay and this result was related to the filling of soil voids with nanoparticles.

Plate 1 which is the natural soil shows an increase in hydraulic conductivity which is in line with the work Viviani and Iovino (2004). The changes could also be due to the lead ions present, the double layer thickness of clay particles is inversely proportional to the concentration and valance notably the soil was compacted at BSH +2 of the OMC where the dispersed particle structure is formed, in that condition, the repulsive forces are dominant and also the diffuse double layer DDL becomes thicker which causes the passage of the liquid to become difficult and thereby lowering hydraulic conductivity these results are in agreement with the study of Sheela and Ajutha (2019). As well, it could also be a result of microbial covering the biofilms and colonies surface of the mineral particles activity leading to a decrease in porosity and pore media which inversely leads to the decrease in hydraulic conductivity as hinted in Osinubi et al. (2020), Tang et al. (2018), Soon et al. (2014), Francisca and Glatstein (2010), and Kanmani et al (2014).

3.2 Microanalysis of Specimens

The provided plates (Plates 7 through 11) showcase the Scanning Electron Microscopy (SEM) morphology and Energy Dispersive X-ray Spectroscopy (EDS) elemental composition of lateritic soil subjected to varying levels of lead () contamination and subsequent electrokinetic (EK) remediation, after being permeated with water and leachate. The comparison across the plates is key to understanding how the EK remediation process and the presence of lead contaminants affect the soil's microstructure and chemistry, ultimately influencing its performance as a landfill liner.

3.2.1 Baseline and Control (Plate 7: Natural Soil, 0% Contamination)

Plate 7 represents the uncontaminated lateritic soil permeated with water and leachate. This serves as the structural and chemical baseline:

- SEM Micrograph: Shows a relatively open and porous microstructure with irregular voids and channels. The soil particles appear to be loosely associated, typical of a flocculated soil fabric.
- EDS Composition: The dominant elements are Silicon (Si) at, Oxygen (O) at, and Iron (Fe) at. As expected for the sample
-

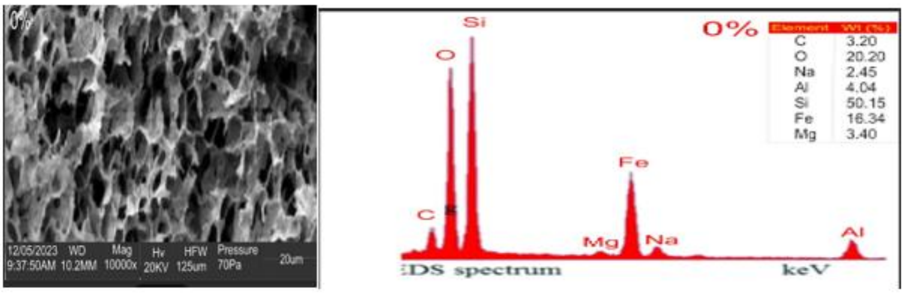

Figure 3. Micrograph Of Lateritic 0% Permeated with Water and Leachate (X 10000 Magnification)

3.2.2. Low Contamination Effect (Plate 8: 0.2% Contamination)

Plate 8 shows the lateritic soil originally contaminated with lead () and then remediated by the EK technique and permeated with water and leachate ().

- SEM Micrograph: Compared to the open structure in Plate 7, the soil appears denser, with the pores significantly reduced in size and number. The structure looks more intertwined and less open to flow.
- EDS Composition: The of Si is, similar to the control. The key finding is the appearance of Nitrogen (N) at and Calcium (Ca). The reduction in porosity suggests that the EK remediation may have induced cementation or precipitation of new phases, contributing to the desired low hydraulic conductivity. The appearance of Ca and N is likely related to the use of treatment chemicals (like EDTA or other components in the leachate/anolyte) that have reacted with the soil.

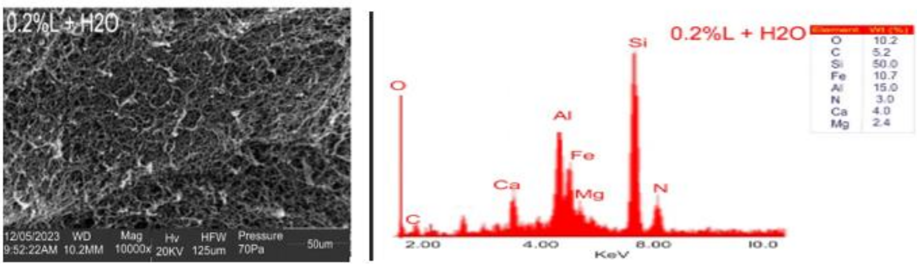

Figure 4. Micrograph Of Electrokinetic Lead Remediated Soil At 0.2% Permeated with Water and Leachate (X 10000 Magnification)

3.2.3. Transition to Granular Structure (Plate 9: 0.4% Contamination)

Plate 9 displays the sample with initial lead contamination after EK remediation and permeation.

- SEM Micrograph: The structure is noticeably more granular and less fibrous than the sample (Plate 8). The soil particles appear as distinct, tightly packed agglomerates, forming a continuous, dense matrix. This highly dense, granular structure is excellent for restricting fluid flow, indicating the remedial process has effectively bound the soil particles into a low-permeability mass.
- EDS Composition: The content is, and is only. There is a corresponding jump in Aluminum (Al) *t*he large swing in and suggests that the remediation process or the contaminating lead concentration may have selectively mobilized or redistributed these major soil components.

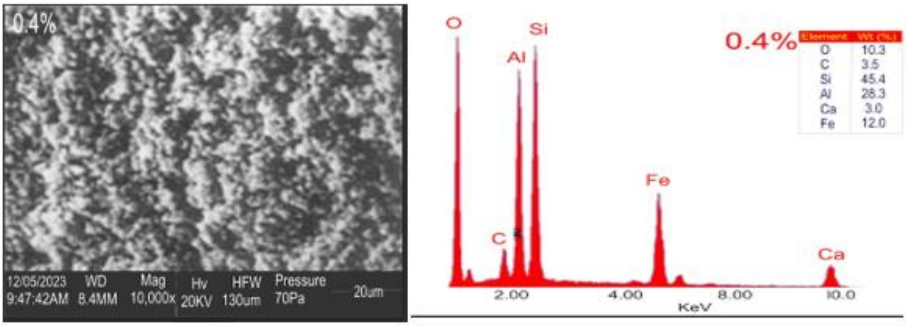

Figure 5. Micrograph of Electrokinetic Lead Remediated Soil At 0.4 % Permeated with Water and Leachate (X 10000 Magnification)

3.2.4. Structural Disruption (Plate 10: 0.6% Contamination)

Plate 10 shows a significant structural departure for the contaminated sample. SEM Micrograph: This image is markedly different, showing large, crevice-like voids or structural planes of failure. The fabric appears to have been pulled apart or strained, creating large preferential flow paths.This structural disintegration suggests that at a initial level, the EK remediation or the lead content itself may have been detrimental to the long-term integrity of the compacted soil structure, potentially increasing the risk of higher hydraulic conductivity.The chemical composition returns to a more Si-rich profile but with a moderate content, indicating the structural issue is more about physical arrangement than simple composition.

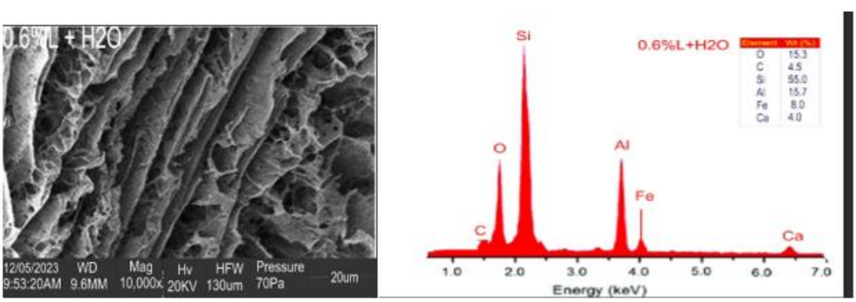

Figure 6. Micrograph Of Electrokinetic Lead Remediated Soil At 0.6% Permeated with Water and Leachate (X 10000 Magnification)

3.2.5. Recovery and High Density (Plate 11: 0.8% Contamination)

Plate 11, representing the initial lead contamination, shows a return to a high-density structure.

SEM Micrograph: The soil fabric is again highly dense and homogenized, resembling the optimal granular structure seen in Plate 9, but perhaps even more packed. The surface is smooth and lacks the major voids seen in the control or the large cracks in Plate 10.

EDS Composition: is high at 9, and is also high at `12, similar to the control. New elements like **Potassium (K) at are** detected. The structure suggests that at this higher contamination level, the chemical reactions (possibly precipitation/cementation enhanced by the EK process) were effective in **creating a robust, impermeable barrier**, despite the initial high content. The high content might be due to localized sampling of quartz-rich areas.

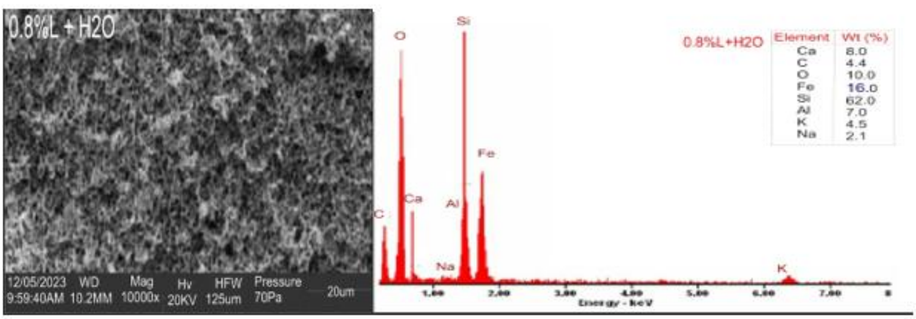

Figure 7. Micrograph Of Electrokinetic Lead Remediated Soil At 0.8% Permeated with Water and Leachate (X 10000 Magnification)

3.2.6. Extreme Contamination (Plate 12: 1.0% Contamination)

SEM Micrograph (Morphology): The structure shows a dramatic return to a highly porous, foam-like structure with large, irregular, and interconnected voids, visually similar to the un-remediated control (Plate 7).

But with a more distinct "cellular" pattern. The return to an open structure suggests that at contamination, the sheer volume of lead contaminant or the intensity of the electrochemical treatment may have overwhelmed the soil's ability to maintain a dense, low-permeability structure. This large degree of porosity would likely result in an unacceptably high hydraulic conductivity, rendering the soil unsuitable for use as a liner at this contamination.

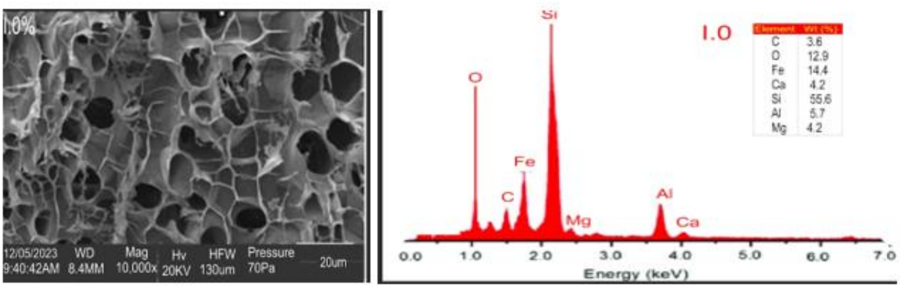

Figure 8. Micrograph Of Electrokinetic Lead Remediated Soil At 1.0% Permeated with Water and Leachate (X 10000 Magnification)

CONCLUSION

The lead contaminated lateritic soil classified as A-7-6 and CH soil according to the AASTHO and USCS soil classification systems respectively were improved to A-2-6 and CL with electrokinetic remediation. The best performance of the remediated soil for liner was with 0.4% leachate and water. As such, 0.4% leachate and water permeated electrokinetic lead remediated soil can be used as liners and cover as a result of the findings in this research.

Overall Conclusion from Microanalysis

The SEM/EDS analysis clearly demonstrates that the suitability of electrokinetic lead-remediated lateritic soil as a liner material is highly dependent on the initial contaminant concentration.

Optimal Performance: Samples with low to moderate initial contamination exhibit the most desirable dense, low-porosity microstructures (Plates 8 and 9).

Critical Thresholds: The structural failure at and the highly porous return at indicate critical thresholds where the remediation process either damages the fabric or is insufficient to enforce low permeability. This microstructural evidence strongly supports the need to use EK remediation only within a specific range of contamination for effective long-term containment.

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