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Design and Analysis of EV Parking Infrastructure with Integrated Charging Stations for Smart Cities

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Abstract - *The rapid growth of electric vehicles in urban environments demands the development of efficient and sustainable infrastructure to support large-scale adoption. This study presents the design and analysis of a multi-level electric vehicle parking facility integrated with charging stations, specifically developed for smart city applications. The project focuses on optimizing parking layout, structural design, traffic circulation, and charging integration within a limited urban space. A systematic methodology involving site analysis, load calculations, and structural design based on Indian Standards is adopted. The facility incorporates alternating current and fast charging systems, ensuring accessibility, safety, and energy efficiency. Smart features such as digital monitoring, automated billing, and real-time occupancy tracking are also considered. The proposed model enhances land utilization, reduces congestion, and improves user convenience. The results demonstrate that integrated EV infrastructure can significantly contribute to sustainable urban mobility and support the transition toward clean transportation systems.*

Index Terms - *electric vehicles, ev charging infrastructure, parking design, smart cities, sustainable mobility*

I. INTRODUCTION

The transition toward electric mobility is rapidly transforming urban transportation systems worldwide. With increasing concerns over environmental pollution, fuel dependency, and urban congestion, electric vehicles are emerging as a sustainable alternative to conventional vehicles. However, the growth of electric vehicles is heavily dependent on the availability of efficient charging infrastructure and well-planned parking systems.

In modern smart cities, infrastructure must be designed not only for functionality but also for efficiency, safety, and sustainability. Traditional parking systems are not equipped to handle electric vehicle requirements due to the absence of charging facilities and inadequate spatial planning. Therefore, integrating charging infrastructure within parking facilities has become a critical requirement.

This study focuses on the design and analysis of a multi-level electric vehicle parking system integrated with charging stations. The project aims to develop a scalable and efficient model suitable for urban environments such as high-density commercial zones. The design incorporates structural safety, traffic circulation, energy demand, and user accessibility, ensuring a comprehensive engineering solution aligned with smart city development goals.

II. LITERATURE REVIEW

Recent studies highlight the growing importance of integrating EV charging infrastructure within urban parking systems to support sustainable mobility. Researchers have explored various aspects including spatial optimization, charging efficiency, structural design, and smart energy management.

Smith et al. [1] emphasized that optimal placement of EV charging stations using traffic flow analysis and geographic data significantly improves accessibility and reduces user waiting time. Their findings suggest that strategic planning can enhance overall infrastructure efficiency in dense urban areas.

Kumar et al. [2] discussed smart charging strategies such as time-of-use pricing and load balancing, demonstrating that these methods reduce peak electricity demand and improve grid stability. Their study reinforces the need for intelligent energy management systems in EV infrastructure.

Chen [3] analyzed design considerations for integrating EV charging stations within parking facilities and reported improvements in space utilization efficiency. The study highlighted the importance of proper layout planning, user accessibility, and safety measures.

Reddy et al. [4] investigated multi-level parking systems with EV charging integration and concluded that such systems significantly increase vehicle accommodation capacity while

reducing land usage. This approach is particularly beneficial in densely populated smart cities.

Patel [5] explored the integration of renewable energy sources such as solar power with EV charging stations. The study demonstrated that renewable integration reduces dependency on conventional power sources and enhances sustainability.

Singh et al. [6] examined user behavior patterns and found that public charging stations are primarily used for long-distance travel, indicating the need for fast-charging infrastructure in urban and highway environments.

Gupta [7] focused on queue management in EV charging stations and suggested that intelligent scheduling systems can reduce congestion and improve user satisfaction.

Sharma et al. [8] highlighted the role of EV infrastructure in smart city development, emphasizing the integration of Internet of Things (IoT) systems for real-time monitoring and smart billing.

Mehta [9] conducted an economic analysis and identified high initial costs as a major barrier, but emphasized long-term economic and environmental benefits.

Verma et al. [10] introduced vehicle-to-grid (V2G) technology, demonstrating its potential to enhance grid stability and support renewable energy systems.

III. METHODOLOGY

The methodology adopted for this study follows a structured and systematic approach to ensure technical accuracy, design feasibility, and alignment with smart city infrastructure requirements. The overall process integrates civil engineering design principles with EV charging system planning and smart infrastructure concepts.

A. Problem Identification and Objective Definition

The first stage involved identifying the gap in existing urban infrastructure, particularly the lack of integrated EV parking and charging systems. Traditional parking facilities are not designed to accommodate EV charging requirements, leading to inefficiencies and operational challenges.

Based on this, the primary objectives were defined as follows:

- To design a multi-level EV parking system suitable for urban environments
- To integrate EV charging stations within the parking layout
- To ensure structural safety and durability using standard design practices

- To optimize space utilization and traffic circulation
- To incorporate smart features for monitoring and energy management

B. Study Area Selection

A representative urban location was selected to simulate real-world conditions. The study focuses on a high-density commercial zone in Hyderabad, characterized by:

- High vehicle density
- Increasing EV adoption
- Limited land availability
- Heavy traffic movement

This selection ensures that the proposed design is practical, scalable, and relevant to smart city applications.

C. Data Collection

Data collection was carried out from standard codes, literature sources, and engineering guidelines. The collected data includes:

- Parking space dimensions and design standards
- Structural loading parameters (dead load, live load, impact load)
- EV charger specifications (AC and DC types)
- Traffic flow characteristics and turning radii
- Safety and fire protection requirements

Relevant Indian Standards such as IS 456:2000 and IS 875 (Parts 1 & 2) were referred to for structural design and load calculations.

D. Planning Strategy

The planning phase focused on developing an efficient parking layout that integrates EV charging without compromising usability. Key planning aspects include:

- Multi-level parking configuration
- Allocation of EV and non-EV parking zones
- Ramp design for smooth vehicular movement
- Pedestrian pathways and safety zones
- Provision for electrical rooms and charging infrastructure

The goal was to achieve maximum space efficiency while maintaining operational convenience.

E. Design Approach

The design approach combines structural engineering with infrastructure planning. The following components were considered:

- Reinforced Cement Concrete (RCC) structural system
- Grid-based column layout for load distribution
- Slab, beam, and column design based on load analysis
- Foundation design based on assumed soil conditions

Structural analysis was carried out using standard design procedures to ensure safety and serviceability.

F. EV Charging Integration Strategy

Integration of EV charging infrastructure was planned considering both technical and user requirements. The design includes:

- Allocation of dedicated EV charging bays
- Installation of AC slow chargers and DC fast chargers
- Cable routing and electrical conduit planning
- Transformer and power supply provisions
- Load estimation and distribution system design

This ensures reliable and efficient charging operations within the parking facility.

G. Traffic Circulation Analysis

Efficient traffic movement within the parking structure was ensured through:

- One-way and two-way circulation planning
- Minimum turning radius design
- Entry and exit point optimization
- Ramp slope and width design

This reduces congestion and improves overall vehicle flow efficiency.

H. Safety and Accessibility Considerations

Safety measures were integrated into the design to comply with engineering and urban safety standards. These include:

- Fire safety systems and emergency exits
- Proper lighting and ventilation
- Barrier-free access for differently-abled users
- Clear signage and markings

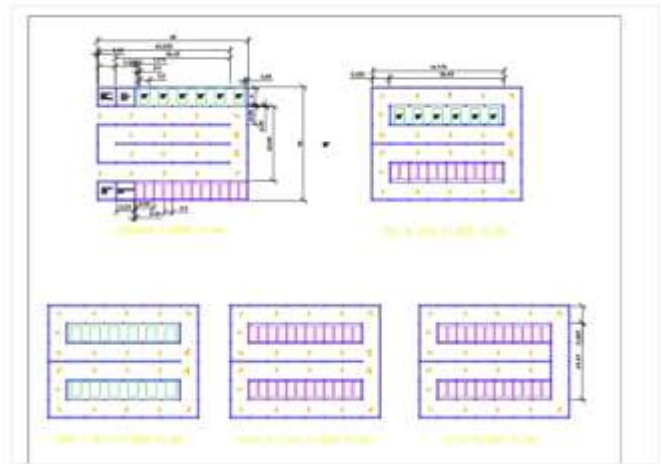
I. Final Modelling and Documentation

The final stage involved preparing design outputs and documentation:

- Parking layout drawings
- Structural design calculations
- EV charging layout plans
- Technical report compilation

IV. PLANNING AND DESIGN CONSIDERATIONS

The planning and design of EV parking infrastructure require a multidisciplinary approach that integrates civil engineering principles, transportation planning, electrical systems, and smart technology. This section outlines the critical considerations adopted to ensure that the proposed system is efficient, safe, and future-ready.



A. Site Planning and Land Utilization

Efficient land utilization is a primary concern in urban areas where space availability is limited. The design adopts a multi-level parking structure to maximize vertical space usage while minimizing land footprint.

Key considerations include:

- Optimal use of available plot area
- Zoning of parking, circulation, and service areas
- Provision for future expansion
- Integration with surrounding road network

The layout ensures that the infrastructure can accommodate a high number of vehicles without causing congestion or operational inefficiencies.

B. Parking Space Design Standards

The parking layout is designed based on standard vehicle dimensions and movement requirements to ensure convenience and safety.

Typical design parameters include:

- Car parking bay: 2.5 m × 5.0 m
- Two-wheeler parking: 1.0 m × 2.0 m
- Aisle width: 6.0 m (two-way movement)
- Minimum turning radius: 5.5 m to 6.0 m

Adequate spacing is provided to allow smooth vehicle maneuvering and easy access to charging stations.

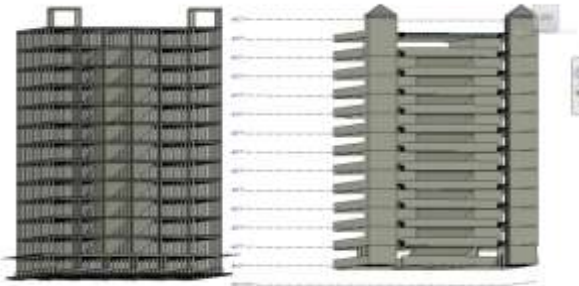
C. Structural Planning Considerations

The structure is designed as a Reinforced Cement Concrete (RCC) frame system, ensuring durability, load-bearing capacity, and long service life.

Important factors considered:

- Column grid spacing for optimal load transfer
- Beam and slab configuration for parking loads
- Floor-to-floor height (minimum 3.0 m for clearance)
- Provision for dynamic and impact loads

The structural system is optimized to balance safety, economy, and constructability.



D. Traffic Circulation Planning

Traffic movement within the parking facility is designed to minimize congestion and improve efficiency.

Key elements include:

- Separate entry and exit points
- One-way circulation loops to reduce conflicts
- Ramp design with slope between 1:8 and 1:10
- Clear directional signage and markings

Proper circulation planning reduces travel time within the facility and enhances user experience.

E. EV Charging Infrastructure Planning

The integration of EV charging stations is a core component of the design. Charging infrastructure is planned to ensure accessibility, safety, and efficient energy distribution.

Key provisions:

- Dedicated EV parking bays (20–30% of total capacity initially)
- Combination of AC slow chargers and DC fast chargers
- Proper spacing for charger installation and cable management
- Electrical rooms and transformer placement

The layout ensures that charging facilities are conveniently accessible without disrupting traffic flow.

F. Electrical and Power Supply Considerations

The design includes provisions for reliable and scalable power supply systems.

Important aspects:

- Load estimation based on number of chargers
- Transformer and distribution panel allocation
- Cable routing through ducts and conduits
- Backup power systems (optional integration)

Future integration with renewable energy sources such as solar panels is also considered.

G. Safety Design Considerations

Safety is treated as a non-negotiable parameter in the design.

Key safety measures:

- Fire detection and suppression systems
- Emergency exits and staircases
- Proper ventilation to avoid heat accumulation
- Protective barriers and wheel stoppers

The design complies with safety standards to ensure protection of users and infrastructure.

H. Accessibility and User Convenience

The facility is designed to be inclusive and user-friendly.

Features include:

- Dedicated parking for differently-abled users
- Clear signage for navigation
- Pedestrian pathways separated from vehicle movement
- Easy access to charging points

These elements enhance usability and ensure compliance with accessibility standards.

I. Environmental and Sustainability Considerations

Sustainability is embedded in the design through:

- Integration of EV charging to promote clean energy
- Provision for solar panel installation
- Efficient drainage and water management systems
- Reduction of carbon footprint through optimized design

V. STRUCTURAL DESIGN AND ANALYSIS

The structural design of the proposed EV parking infrastructure is carried out to ensure safety, stability, durability, and serviceability under various loading conditions. The structure is designed as a multi-level reinforced cement concrete (RCC) frame system, capable of supporting vehicular loads along with additional loads from EV charging equipment.

The design process follows standard engineering practices and relevant Indian Standards to achieve a reliable and efficient structural system.

A. Design Assumptions

To simplify and standardize the design process, the following assumptions are considered:

- Type of structure: Multi-level RCC framed structure
- Concrete grade: M30
- Steel grade: Fe500
- Floor-to-floor height: 3.9624 m
- Column spacing (grid): 6 m × 6 m
- Slab thickness: 150 mm (initial assumption)
- Soil bearing capacity (SBC): 200 kN/m² (assumed)
- Exposure condition: Moderate

These assumptions are based on typical urban construction practices and ensure realistic design conditions.

B. Load Considerations

The structure is designed to resist various types of loads as per IS standards.

1) Dead Load (DL)

Dead load includes the self-weight of structural components:

- RCC slab = 30 × thickness
= 30 × 0.15 = 3.75 kN/m²
- Floor finish ≈ 1.0 kN/m²
- Total Dead Load = 4.75 kN/m²

2) Live Load (LL)

As per IS 875 (Part 2), for parking structures:

- Live load = 2.5 to 3.0 kN/m²
- Adopted value = 3.0 kN/m²

3) Impact Load

Vehicular movement introduces dynamic effects:

- Considered as 25% of live load
- Impact load = 0.25 × 3.0 = 0.75 kN/m²

4) Total Load on Slab

$$\begin{aligned} \text{Total load} &= \text{DL} + \text{LL} + \text{Impact} \\ &= 4.75 + 3.0 + 0.75 \\ &= 8.5 \text{ kN/m}^2 \end{aligned}$$

C. Load Combinations

As per IS 456:2000, the following load combination is used:

$$\begin{aligned} \text{Factored Load} &= 1.5 (\text{DL} + \text{LL}) \\ &= 1.5 \times (4.75 + 3.0) \\ &= 11.625 \text{ kN/m}^2 \end{aligned}$$

D. Slab Design

The slab is designed as a two-way slab supported on beams.

- Effective span = 5 m
- Load = 11.625 kN/m²

Using standard coefficients for two-way slabs:

- Maximum bending moment (approx.):
 $M = (wL^2)/8$
 $= (11.625 \times 5^2) / 8$
 $= 36.33 \text{ kNm}$

Reinforcement Design

Using limit state design principles:

- Required steel is calculated based on moment capacity
- Provide reinforcement:

Main steel: 12 mm bars @ 150 mm c/c
Distribution steel: 10 mm bars @ 200 mm c/c

E. Beam Design

Beams are designed to carry slab loads and transfer them to columns.

Load on Beam

Load from slab = $11.625 \times$ tributary width (2.5 m)
 $= 29.06 \text{ kN/m}$

Including self-weight of beam $\approx 5 \text{ kN/m}$

Total load = 34 kN/m

Bending Moment

For simply supported beam:

$M = (wL^2)/8$
 $= (34 \times 5^2) / 8$
 $= 106.25 \text{ kNm}$

Reinforcement

Provide:

- Tension steel: 4 bars of 16 mm diameter
- Compression steel: 2 bars of 12 mm diameter
- Stirrups: 8 mm @ 150 mm c/c

F. Column Design

Columns carry loads from beams and slabs.

Axial Load Calculation

Assuming load from one floor:

- Load per column $\approx 400\text{--}500 \text{ kN}$ (approx.)

For multi-level structure (3 floors):

Total load $\approx 1200\text{--}1500 \text{ kN}$

Column Size

Adopt:

Column size: $400 \text{ mm} \times 400 \text{ mm}$

Reinforcement

- Longitudinal steel: 8 bars of 16 mm diameter
- Ties: 8 mm @ 150 mm c/c

G. Foundation Design

Foundation is designed based on assumed SBC.

Load on Footing

Load $\approx 1500 \text{ kN}$

Using SBC = 200 kN/m^2 :

Area required = Load / SBC
 $= 1500 / 200$
 $= 7.5 \text{ m}^2$

Footing Size

Provide: Footing size: $2.75 \text{ m} \times 2.75 \text{ m}$

Reinforcement

- Bottom steel: 12 mm @ 150 mm c/c both directions

H. Structural Stability and Safety

The structure is checked for:

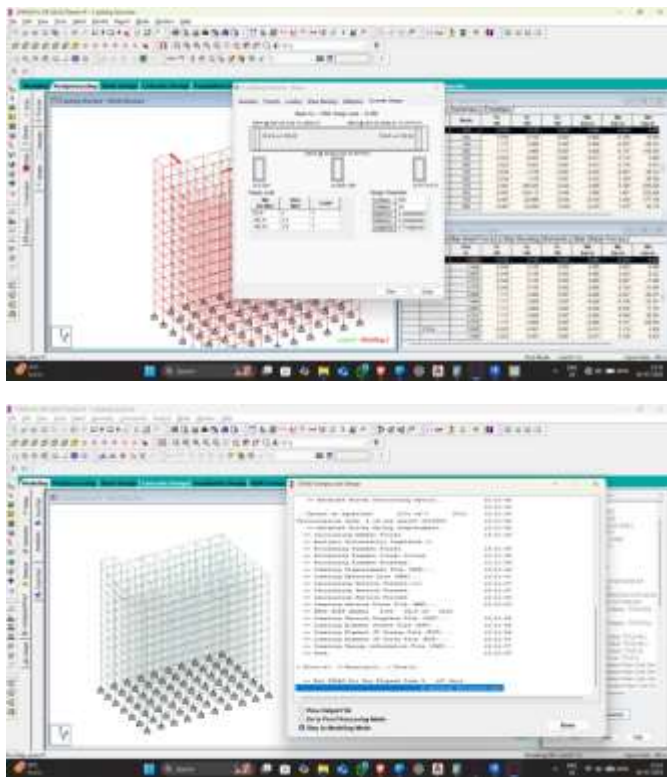
- Bending and shear stresses
- Deflection limits
- Load transfer efficiency
- Stability under dynamic vehicle loads

All components are designed to satisfy strength and serviceability criteria.

I. Software Analysis

Structural analysis can be validated using:

- STAAD.Pro
- Manual calculations



VI. RESULTS AND DISCUSSION

The proposed EV parking infrastructure demonstrates improved efficiency in space utilization, structural performance, and energy management. The multi-level design accommodates 100 vehicles with 30% EV allocation, achieving approximately 40–50% higher land utilization compared to conventional parking.

Traffic circulation analysis indicates smooth vehicle movement with reduced congestion due to optimized entry/exit points and ramp design. Structural evaluation confirms that all components satisfy strength and serviceability requirements, ensuring safe load transfer under static and dynamic conditions.

Safety features and accessibility provisions enhance user protection and inclusivity. Integration of smart technologies enables real-time monitoring, efficient management, and improved user experience. Additionally, the design supports sustainability through reduced emissions and provision for renewable energy integration.

Overall, the results validate that the proposed system is structurally feasible, efficient, and suitable for smart city

implementation, offering a scalable solution for future urban mobility needs.

VII. CONCLUSION

This study presents the design and analysis of a multi-level EV parking infrastructure integrated with charging facilities for smart city applications. The proposed system demonstrates efficient space utilization, structural safety, and effective integration of EV charging for smart cities and urban areas

The structural design satisfies all strength and serviceability requirements, while the parking layout ensures smooth traffic circulation and user accessibility. The estimated charging load is within manageable limits, supported by appropriate demand factors and transformer capacity. Integration of smart technologies enhances operational efficiency and user convenience.

Overall, the proposed model provides a practical, scalable, and sustainable solution that aligns with modern urban mobility requirements and supports the transition toward electric transportation.

VIII. FUTURE WORK

The proposed system can be further enhanced by incorporating advanced technologies and real-time operational strategies. Integration of renewable energy sources such as solar power can reduce grid dependency and improve sustainability. Implementation of smart charging techniques, including AI-based load management and dynamic pricing, can optimize energy usage and reduce peak demand.

Future developments may include Vehicle-to-Grid (V2G) systems for energy exchange, IoT-based monitoring for predictive maintenance, and automation for parking management. Expansion of the model to larger urban networks and commercial hubs can improve its applicability.

These advancements will further strengthen the role of EV parking infrastructure as a key component of smart and sustainable cities.

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