Designing and Managing Smart Parking Systems: A Comprehensive Analysis of Surat Railway Station

[1]M.A.Pathan , [2]Maaz Bandi
[1]Lecturer, [2]Student
[1]Applied Mechanics
[1]Government Polytechnic, Ahmedabad, India

Abstract : This research presents a comprehensive analysis of parking management challenges and smart parking solutions at Surat Railway Station, India. Through detailed field surveys using the license plate method and geometric increase forecasting techniques, this study evaluates current parking capacity, demand patterns, and revenue generation while proposing sustainable infrastructure solutions. The research reveals an 87.5% overall capacity utilization rate with significant revenue generation potential of Rs. 17,150 daily from current facilities. The study proposes a multi-story parking infrastructure that would increase capacity by over 200% for two-wheelers and 100% for four-wheelers, addressing projected demand growth through 2025. The findings contribute to the growing body of knowledge on smart parking systems in developing countries and provide a framework for similar transportation hubs across India.

IndexTerms- Smart parking systems, railway station parking, urban transportation, parking management, license plate survey, demand forecasting.

1. INTRODUCTION

Urban transportation infrastructure in India faces unprecedented challenges due to rapid urbanization and increasing vehicle ownership. Railway stations, serving as critical transportation hubs, experience particularly acute parking shortages that impede efficient multimodal connectivity . The parking crisis in Indian cities has reached a critical point, with congestion, illegal parking, and inadequate infrastructure creating significant urban challenges [3].Surat Railway Station, the second-highest revenue-generating station in the Mumbai Division of Western Railways, exemplifies these challenges. Built in 1860 and serving as a major transportation node for Gujarat's textile and diamond industries, the station handles substantial passenger traffic requiring efficient parking management [4]. The increasing number of private vehicles, driven by inadequate public transportation and rising incomes, has created a parking demand that exceeds current supply capabilities.This research addresses the critical need for data-driven parking management solutions at Surat Railway Station. The study employs comprehensive field surveys and advanced forecasting techniques to analyze current parking patterns, evaluate revenue generation potential, and propose sustainable infrastructure improvements. The findings provide insights applicable to similar transportation hubs across India's rapidly urbanizing landscape.

2. LITERATURE REVIEW

A comprehensive review of published studies reveals significant advancements in understanding the behavior of concrete under elevated temperature conditions. The following summarizes key findings relevant to both normal strength concrete (NSC) and high strength concrete (HSC). **M.V. Krishna Rao et al.** [1] investigated M40 grade concrete subjected to sustained temperatures of 150°C, 300°C, and 450°C under different curing methods. Their findings indicated a consistent reduction in compressive strength and mass with increasing temperature, regardless of the curing approach. **Kim et al.** [2] conducted tests on HSC with compressive strengths of 40, 60, and 80 MPa. Results showed a marked reduction in both compressive strength and elastic modulus when exposed to temperatures between 200°C and 700°C. They observed that the compressive strength could decrease by as much as 20%. **Ikponmwosa and Salau** [3] examined laterised concrete (with varying laterite-sand replacement ratios) exposed to 250°C, 500°C, and 750°C. Their results demonstrated that concrete with 25% laterite maintained superior strength up to 500°C, whereas normal concrete experienced failure beyond 250°C. **Ghani et al.** [4] reported that concrete cured at elevated temperatures (up to 550°C) exhibited improved tensile strength at lower water-cement ratios, although the modulus of rupture decreased, suggesting compromised flexural capacity. **Phan** [5] analyzed explosive spalling in HSC using 100 mm × 200 mm cylindrical specimens. A lower water-to-cement ratio (0.22) correlated with minimized strength loss and reduced spalling risk, especially under compressive stresses up to 40% of the original room temperature strength. **Kulkarni et al.** [6] provided a comprehensive overview of high-performance concrete (HPC) behavior under fire exposure, summarizing various predictive models for mechanical degradation and structural performance. **Bishr** [7] studied silica fume-modified concrete exposed to temperatures up to 900°C. Although silica fume enhanced early-age strength, it led to greater sensitivity to thermal damage, with compressive strength retention ranging between 62% and 81% of the original strength at maximum exposure. **Javadian et al.** [8] compared plain and steel fiber-reinforced concrete exposed to 300°C, 450°C, and 650°C. While fiber-reinforced concrete initially exhibited higher flexural strength, the difference diminished at elevated temperatures due to softening of steel fibers. **Tolentino et al.** [9] examined M45 and M60 concretes exposed to 600°C. Post-cooling analysis revealed a decrease in residual compressive strength and modulus of elasticity, attributing performance degradation to microstructural damage from thermal exposure. **Yüzer et al.** [10] explored the correlation between visual color change and compressive strength loss in mortar samples exposed to 100–1200°C. Findings suggest that color change can serve as a nondestructive indicator of thermal damage. **Savva et al.** [11] investigated concrete mixes containing 10% and 30% pozzolanic replacements using natural pozzolana and lignite fly ash. Samples were exposed to 100°C to 750°C. Using rebound hammer and ultrasonic pulse velocity methods, they found that pozzolanic concretes retained strength and exhibited lower thermal degradation compared to control mixes. Collectively, these studies underscore the influence of temperature on the mechanical behavior of concrete. High strength concretes, though generally more durable, are susceptible to sudden spalling and internal cracking. The use of supplementary cementitious materials and low W/C ratios can mitigate some of the negative thermal effects.

3. METHODOLOGY

This study aims to evaluate the influence of elevated temperatures on the compressive strength of both Normal Strength Concrete (NSC) and High Strength Concrete (HSC). The experimental methodology includes mix design, specimen casting, controlled heating, and compressive strength testing as per standardized procedures.

3.1 Concrete Grades and Mix Design

Concrete mixes of six different grades were prepared: M20, M30, M40, M50, M60, and M70. The mix proportions were designed using the Indian Standard method as per IS 10262:2009 [12], considering a targeted slump of 75–100 mm for good workability. The water-cement ratios were selected based on the desired grade, with adjustments made for strength gain and durability requirements. For high strength mixes (M50 and above), a sulfonated naphthalene-based superplasticizer (Hypo superplasticizer) was added to enhance workability and reduce water demand. The mix designs accounted for surface-dry conditions of aggregates, with corrections applied for moisture content.

3.2 Materials

- **Cement**: 43-grade Ordinary Portland Cement (OPC) conforming to IS 12269:1987 was used.
- **Fine Aggregates**: Locally sourced river sand conforming to Zone III of IS 383:1970.
- **Coarse Aggregates**: Crushed granite stone of maximum size 20 mm.
- **Water**: Potable water was used throughout the process.
- **Admixtures**: Hypo superplasticizer was used for M50, M60, and M70 grades at dosages ranging from 3.89 to 6.30 L/m³.

3.3. Specimen Preparation and Curing

Concrete cubes of size 150 mm × 150 mm × 150 mm were cast using steel moulds. A total of 216 cubes were prepared for six concrete grades at two curing ages (7 and 28 days) and six different temperature exposure levels (30°C, 50°C, 100°C, 150°C, 200°C, and 250°C).After demoulding at 24 hours, the specimens were cured in clean water tanks maintained at ambient temperature. Following the curing period, the specimens were air-dried before temperature treatment.

3.4. Temperature Exposure Protocol

For thermal conditioning, the specimens were placed in an electric oven and heated to designated target temperatures (50°C to 250°C) for a duration of 1 hour. Heating was conducted in a controlled environment without applying any external load. After exposure, the specimens were allowed to cool naturally to room temperature in air.

3.5. Compressive Strength Testing

The compressive strength tests were carried out in accordance with IS 516:1959 [13]. A calibrated compression testing machine (CTM) with a loading capacity of 2000 kN was used. The load was applied continuously and uniformly at a rate of 140 kg/cm²/min until failure. Three specimens were tested for each temperature and curing age combination, and the average strength was recorded.

3.6. Data Analysis

The percentage variation in compressive strength relative to the control specimens (tested at 30°C) was computed for each temperature level. Separate analyses were conducted for 7-day and 28-day cured specimens to assess the early and long-term effects of thermal exposure. Graphs were plotted for each grade to visualize the strength-temperature relationship.

4. EXPERIMENTAL SETUP

4.1. Materials and Their Properties

All materials used in this study were sourced locally and characterized as per relevant Indian Standards.

- **Cement**: 43 Grade Ordinary Portland Cement (OPC) conforming to IS 12269:1987 was used throughout the study. The cement exhibited a normal consistency of 33%, an initial setting time of 48 minutes, and a 28-day compressive strength of 45 MPa.
- **Fine Aggregates**: Locally available river sand was used as fine aggregate. It was washed, sieved through a 4.75 mm IS sieve, and tested as per IS 383:1970. It belonged to grading Zone III, with a specific gravity of 2.46 and fineness modulus of 2.56.
- **Coarse Aggregates**: Crushed granite aggregates with a maximum nominal size of 20 mm were used. They had a specific gravity of 2.66, a fineness modulus of 6.83, and water absorption of 0.56%.
- **Water**: Potable water fit for drinking and free from harmful contaminants was used for both mixing and curing.
- **Admixtures**: For high strength concrete (grades M50 and above), a brown-colored hypo superplasticizer containing organic material was used. It offered water reduction up to 25%, enabling better workability at lower water-cement ratios.

4.2. Concrete Mix Proportions

Concrete mix designs were prepared using IS 10262:2009 and IS 456:2000 guidelines.Table I provides the quantities of materials required for different concrete grades.

Grade	Cement (kg)	Sand (kg)	Coarse Aggregate (kg)	Water (L)	W/C Ratio	Superplasticizer (L)
M20	383	546	1188	191.5	0.50	–
M30	390	810	998	185	0.47	–
M40	400	660	1167	160	0.40	6.30
M50	422	621	1284	185	0.35	5.06
M60	504	683	1108	142	0.29	4.67
M70	513	616	1108	154	0.30	3.89

Table I ***Mix Proportions for 1 m³ of Concrete***

4.3. Casting and Curing

Cubes of dimensions 150 mm × 150 mm × 150 mm were cast for each concrete grade. The concrete was mixed using a mechanical mixer to ensure uniformity. The fresh concrete was poured into steel moulds in three layers and compacted using a table vibrator.After demoulding at 24 hours, the specimens were submerged in clean water and cured for either 7 or 28 days. Care was taken to maintain consistent curing conditions to avoid any premature drying or thermal shocks.

4.4. Thermal Conditioning

Post-curing, the specimens were air-dried and exposed to target temperatures of 50°C, 100°C, 150°C, 200°C, and 250°C using an electrically controlled oven. The room temperature (30°C) served as the control condition.Each specimen was heated for one hour at the designated temperature. After thermal exposure, the specimens were allowed to cool naturally to ambient conditions before testing.

4.5. Compressive Strength Testing

The compressive strength of each specimen was determined as per IS 516:1959. Testing was performed using a calibrated Compression Testing Machine (CTM) with a capacity of 2000 kN.Specimens were placed centrally between the CTM platens, and the load was applied at a uniform rate of 140 kg/cm²/min until failure. The failure mode (cracking, crushing, or shearing) was visually inspected, and any anomalies were recorded.Three cubes were tested for each grade, temperature, and curing period. The average compressive strength was calculated and used for comparative analysis.

5. RESULTS AND DISCUSSION

This section presents the experimental findings on the effect of elevated temperatures (30°C–250°C) on the compressive strength of concrete grades ranging from M20 to M70, evaluated at both 7 and 28 days of curing. The results are analyzed to assess thermal resistance and degradation trends for Normal Strength Concrete (NSC) and High Strength Concrete (HSC).

5.1. Compressive Strength at 7 Days

For all concrete grades, an increase in compressive strength was observed when specimens were heated up to 50°C. Beyond this threshold, strength began to decline with increasing temperature. The 7-day compressive strength for M20 increased by approximately 8%, while M70 increased by around 3% at 50°C. However, at 250°C, M20 exhibited a reduction of 22%, and M70 showed a smaller reduction of approximately 0.72%, indicating that HSC retained its strength more effectively under thermal stress in early-age curing.

5.2. Compressive Strength at 28 Days

The 28-day compressive strength showed a consistent declining trend with increasing temperature across all concrete grades. This decline is attributed to microstructural damage due to dehydration of calcium silicate hydrates (C-S-H) and the development of thermal cracks.As shown in **Fig. 1**, the compressive strength of M20 dropped from 23.00 MPa at 30°C to 18.87 MPa at 250°C, amounting to a 21.9% reduction. In contrast, M70 dropped from 71.78 MPa to 66.50 MPa, a reduction of only 7.9%. These findings suggest that HSC exhibits higher thermal stability due to lower porosity and the presence of pozzolanic admixtures.

5.3. Comparative Analysis of Temperature Resistance

Fig. 1 presents the compressive strength vs. temperature relationship for all grades at 28 days. A near-linear decline is observed for NSC grades (M20–M40), while HSC grades (M50–M70) display a relatively flatter slope, indicating better thermal endurance.

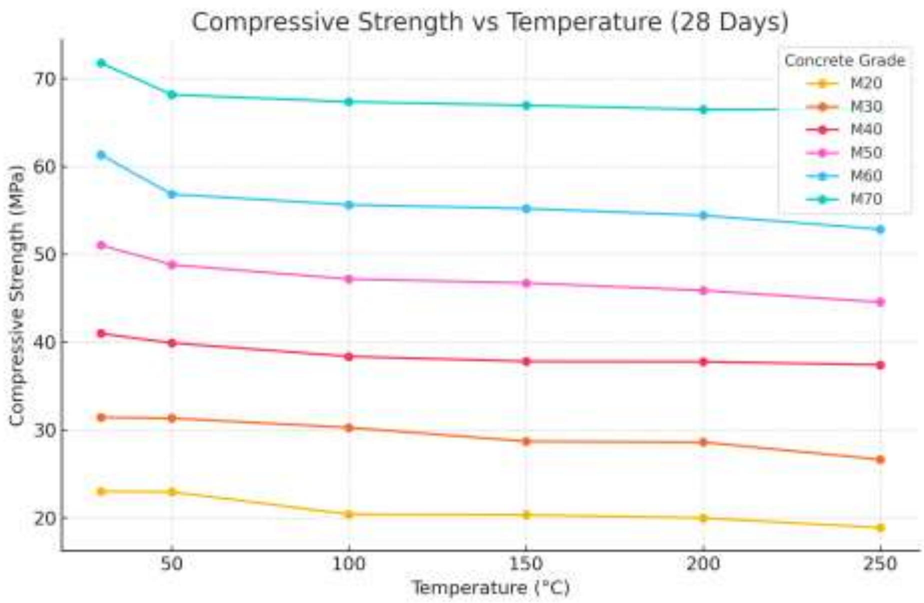

Fig. 1. Compressive Strength vs. Temperature at 28 Days for M20–M70 Grades

Table II summarizes the 28-day compressive strength values for all concrete grades at each temperature level.

Table II. 28-Day Compressive Strength (MPa) for Varying Temperatures

Temperature (°C)	M20	M30	M40	M50	M60	M70
30	23.00	31.43	40.98	51.03	61.33	71.78
50	22.95	31.33	39.90	48.80	56.83	68.17
100	20.40	30.27	38.37	47.18	55.63	67.35
150	20.33	28.70	37.80	46.73	55.20	66.95
200	19.97	28.60	37.77	45.88	54.42	66.48
250	18.87	26.63	37.40	44.55	52.85	66.50

5.4. Interpretation of Results

- **Thermal Gain at 7 Days**: Mild heat exposure (up to 50°C) enhanced hydration, improving early strength in both NSC and HSC.
- **Thermal Degradation at 28 Days**: Long-term strength decreased with temperature. The effect was more pronounced in NSC due to higher permeability and water loss.
- **HSC Stability**: HSC grades retained over 90% of original strength even at 250°C, due to lower water-binder ratios and dense matrix formation.

5.5. Failure Mode Observation

Cubes exposed to higher temperatures exhibited surface discoloration, microcracks, and brittle failure. NSC samples showed more pronounced surface cracks and spalling, while HSC retained better surface integrity.

6. CONCLUSION

This study systematically investigated the influence of elevated temperatures on the compressive strength of Normal Strength Concrete (NSC) and High Strength Concrete (HSC), covering grades M20 through M70. Concrete specimens were cured for 7 and 28 days and subjected to temperature exposures ranging from 30°C to 250°C. The key conclusions were drawn from the experimental results are at **7 days of curing**, all concrete grades exhibited an increase in compressive strength when exposed to 50°C. The strength gain ranged from **8% to 16% for NSC** and **3% to 10% for HSC**, attributed to accelerated hydration under mild thermal activation. Beyond 50°C, strength reductions were observed. At 250°C, the **7-day compressive strength declined by 13% to 22% for NSC**, whereas **HSC showed a comparatively lower reduction of 3% to 8%**, indicating better early-age thermal resilience. **At 28 days of curing**, all concrete grades emonstrated a consistent decrease in compressive strength with increasing temperature. **NSC grades experienced up to 22% strength loss**, while **HSC grades retained more than 90% of their original strength**, with losses ranging between 7% and 10%. The superior performance of HSC at elevated temperatures can be attributed to its **low water-cement ratio**, **reduced porosity**, and **use of superplasticizers**, which contribute to a denser and more thermally stable matrix. The compressive strength vs. temperature plots confirm that **HSC exhibits a more gradual decline**, making it more suitable for applications involving moderate thermal exposure, such as structures near furnaces, fire-prone zones, or industrial plants. These findings reinforce the suitability of HSC in thermal environments and provide insight into the thermal behavior of concrete for structural design and fire safety considerations.

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