



## Analysis and Design of Multi-Level Parking Structures Under Dynamic Loads

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### Abstract

Rapid urbanization and increasing vehicle ownership have intensified the demand for efficient multilevel parking facilities in urban areas. This study analyzes the seismic performance of a G+7 multilevel parking structure using Reinforced Cement Concrete (RCC) and Steel-Concrete Composite construction in ETABS-2015. The analysis considers dynamic loading conditions for a site at Chhatrapati Sambhajinagar (Paithan Gate), following IS 1893:2002 seismic provisions. Structural performance is evaluated based on storey displacement, storey drift, modal participation ratio, and fundamental time period. The results indicate that the composite structure performs better than the RCC structure by exhibiting lower displacement, reduced storey drift, higher modal participation, and greater stiffness while satisfying IS 456:2000 serviceability limits. The study concludes that steel-concrete composite construction is a more efficient and reliable solution for multilevel parking structures, offering improved seismic performance and supporting sustainable urban infrastructure development.

**Keywords:** Multilevel parking; Composite structure; Dynamic analysis; Seismic performance.

### 1. Introduction

The number of vehicles in Indian cities has increased rapidly over the last few years, creating serious parking problems. In cities such as Aurangabad (Chhatrapati Sambhajinagar), the growing number of vehicles has led to traffic congestion, shortage of parking spaces, and inconvenience for road users. As of November 2021, the district had more than 14 lakh registered vehicles, including over 88,000 four-wheelers. Due to the lack of proper parking facilities and organized parking management, many vehicles are parked on roadsides, reducing road width and causing delays, accidents, and inconvenience to pedestrians.

The parking problem is more severe in busy commercial areas such as Paithan Gate, where a large number of people visit daily for shopping and business activities. Drivers spend a considerable amount of time

searching for parking spaces, which increases traffic congestion, fuel consumption, and air pollution.

Conventional parking methods, such as parallel, perpendicular, and angle parking, require a large amount of land. Since land is limited and expensive in urban areas, multilevel parking structures have become an effective solution. These structures use vertical space to accommodate more vehicles within a smaller land area, making them suitable for densely populated commercial locations.

The structural system plays an important role in the safety and performance of multilevel parking buildings. These structures must safely resist dead loads, live loads, vehicle loads, and earthquake forces. Reinforced Cement Concrete (RCC) is widely used in India because of its durability and availability. However, Steel-Concrete Composite construction is becoming increasingly popular due to its higher strength, better stiffness, smaller structural members, and faster construction. Composite structures combine the compressive strength of concrete with the tensile strength of steel, resulting in improved structural efficiency.

This study proposes a G+7 multilevel parking structure at Paithan Gate, Aurangabad (Chhatrapati Sambhajinagar), to help address the city's parking problems. The parking structure is analysed using ETABS-2015 under dynamic loading conditions. A comparative study is carried out between RCC and Steel-Concrete Composite structures based on important structural parameters such as storey displacement, storey drift, modal participation ratio, and fundamental time period. The seismic performance of both structural systems is also evaluated for Zone-II conditions according to the relevant Indian Standard codes.

The main objectives of this study are:

- a. To identify the major parking problems in Aurangabad (Chhatrapati Sambhajinagar).
- b. To develop the planning and design of a G+7 multilevel parking structure.
- c. To compare the structural performance of RCC and Steel-Concrete Composite systems.
- d. To evaluate the seismic behaviour of both structural systems under dynamic loading.

The findings of this research will help structural engineers, planners, and policymakers select suitable structural systems for safe, economical, and sustainable multilevel parking facilities in rapidly growing urban areas.

## 2. Literature Review

### 2.1. Parking Infrastructure Studies

Anthony Nkem Ede and Peace Feyiyemi Adepoju (2015) [1] studied the design of a multi-storey car parking structure in Nigeria using Orion R16 software. Their research focused on a four-storey parking building with a capacity of 1,200 vehicles over an area of 7,660 m<sup>2</sup>. The design followed British Standards (BS Codes). The study highlighted the importance of proper planning, including ramps, emergency exits, car wash facilities, and mechanical service areas. Structural analysis was carried out using the finite element method, where slab loads were transferred to supporting beams for safe load distribution.

Abdul Qayyum and Arun Kumar (2017) [2] discussed the important design aspects of multi-storey parking structures, such as parking layout, ramp dimensions, parking bay size, aisle width, and structural grid planning. They emphasized the need for good security, proper visibility, sufficient circulation space, and lift

facilities to improve user convenience. Their study concluded that multi-storey parking systems are an effective solution for saving land in urban areas. They also recommended that parking buildings with 400–500 vehicle capacity and up to five floors provide efficient operation and traffic management.

B. Vamsi (2017) [3] designed and analysed a multi-storey parking structure using STAAD Pro software based on IS 456:2000. The study proposed a parking facility at Jagadamba Centre and concluded that it could significantly reduce traffic congestion and meet parking demands for nearly ten years. The research demonstrated the effectiveness of multilevel parking as a practical solution for growing urban traffic problems.

Dr. S. Mahendran and K. Sivasubramanian (2018) [4] developed an automatic multi-storey parking system to reduce land requirements and improve parking efficiency. The structural layout was prepared using AutoCAD, while structural analysis was performed in STAAD Pro considering both vertical and horizontal loads. The design of structural elements such as slabs, beams, columns, footings, staircases, and ramps was carried out according to IS 456:2000. The study showed that automated parking systems can efficiently utilize available space while ensuring structural safety.

## **2.2. Comparative Studies of Structural Systems**

Mir Abdul Kuddus, Partha Pritom Dey (2017) [5] conducted a cost analysis of RCC, steel, and composite multi-storied car parking structures in Bangladesh. Using ETABS 2013 software, the researchers compared structural parameters and estimated costs for 19-storied frames. The composite construction option provided approximately 25% less cost compared to RCC and 18% less than steel structures, with better structural behavior.

Venkateshwar Reddy (2019) [6] compared seismic performance of 3D (G+3) storey RCC, steel, and composite buildings in earthquake Zone V. Using ETABS 2015 with Equivalent Static Method and Response Spectrum Method, the study concluded that RCC construction is best suited for low-rise buildings among the three types.

Anil S. Savadi (2019) [7] compared RCC, steel, and composite structures for commercial buildings, finding that composite beams are 1.7% less expensive than steel structures and 13.7% less than RC structures. The study highlighted advantages including no requirement for bar bending and formwork, reduced labor requirements, and better deflection criteria.

Phatale Swarup Sanjay (2019) [9] compared seismic response of G+8 storey RCC, steel, and composite frames in earthquake Zone-V using ETABS 2015. The comparative study concluded that RCC construction is best suited for low-rise buildings among all three types.

## **2.3. Design and Analysis Tools**

Pravinkumar, Pramodkar (2018) [10] utilized ETABS software for analysis and design of commercial buildings, performing static analysis and design according to IS 456:2000 guidelines. The study demonstrated the software's capabilities for both steel and RC structure design, including graphic input and modification, 3D model creation, and automated load combinations.

Ankit Kumar (2021) [11] performed dynamic analysis of G+7 storey commercial buildings with uniform and optimized sections in seismic Zone IV using Response Spectrum Analysis method in ETABS. The study

compared results including time period, maximum story displacement, maximum shear, and maximum storey for four models.

The comprehensive review reveals several key findings:

- a. Increasing vehicle populations in cities necessitate efficient parking solutions that minimize land use
- b. Traditional parking methods require considerable area, making multilevel solutions essential
- c. Steel-concrete composite construction offers cost advantages and better structural performance
- d. ETABS is a powerful tool for 3D modeling and structural analysis of buildings
- e. Seismic performance varies significantly among RCC, steel, and composite structures
- f. Smart city initiatives require integrated parking solutions with modern construction technology

### **3. Methodology**

#### ***3.1. Site Selection and Survey***

Based on preliminary surveys of potential locations in Aurangabad (Chhatrapati Sambhajanagar), three sites were evaluated: Paithan Gate, Samarth Nagar, and Narali Bagh. Paithan Gate was selected due to its irregular shape, smaller area, and critical location in the main market area with heavy traffic congestion. The site area measures 1010.41 sq.m, verified using both total station survey and Google Earth Pro software

#### ***3.2. Layout Planning***

- The G+7 parking structure is designed to accommodate: 16 cars per floor (total 112 cars), 15 motorized two-wheelers per floor (total 105 two-wheelers), Alternative capacity: 15 four-wheelers or 60 two-wheelers per floor
- The layout includes: Parking slots with dimensions based on IS recommendations, Circulation paths, Ramp arrangements for vehicle movement between floors
- Lift for vertical movement- Headroom of 2.7m with 2m clearance at the top

#### ***3.3. Structural Modeling***

The structure was modeled using ETABS-2015 software. Key parameters for RCC modeling are presented in Table 1.

**Table 1:** Parameters Considered for RCC Modelling

Sr.No	Particular	Dimension/Value
1	Area dimension	1010.40 sq.m
2	Total height of structure	18.2 m
3	Height of each story	2.7 m
4	Thickness of RCC Slab	150 mm
5	Grade of Longitudinal bar	Fe500
6	Grade of Lateral ties	Fe415
7	Grade of concrete column	M25
8	Grade of concrete beam	M20
9	Grade of concrete slab	M20
10	Density of Concrete	25 KN/m <sup>3</sup>
11	Size of Column C1	450x600 mm
12	Size of Column C2	450x450 mm
13	Size of Beam B1	400x450 mm
14	Seismic zone	II
15	Importance factor	1.0
16	Zone factor	0.5
17	Damping ratio	5%
18	Floor finish	1 kN/m <sup>2</sup>
19	Live load	4 kN/m <sup>2</sup>

For composite structure, equivalent steel sections were designed with composite action between steel beams and concrete deck.

### 3.4. Software Modeling Procedure

The ETABS-2015 modeling involved the following steps:

- Model Creation: Importing architectural coordinates from AutoCAD and defining grid systems
- Property Definition: Assigning material properties and section sizes for beams, columns, and slabs
- Support Conditions: Fixed supports at the base for columns
- Load Application: Defining load patterns including dead load, live load, floor finish, vehicle load, and seismic loads
- Analysis: Running static and dynamic analysis with error checking
- Result Extraction: Obtaining displacement, drift, modal participation ratio, and time period result

## 4. Results and Analysis

The maximum storey displacement values for both composite and RCC structures are presented in Table 2.

Table 1: Maximum Storey Displacement Difference Between X and Y Direction

Sr.No	Particular	Dimension/Value	
Story	Elevation (m)	Composite (mm)	RCC (mm)
Story7	18.2	14.1	16
Story6	16.2	9	14
Story5	13.5	8.2	13.4
Story4	10.8	7	12.3
Story3	8.1	5.3	10.9
Story2	5.4	3.2	8.8
Story1	2.7	1.2	5.9
Base	0	0	0

The analysis reveals:

- Composite structure shows lower displacement values at all storeys
- Maximum displacement at top storey: 14.1 mm (composite) vs 16 mm (RCC)
- Both values are well within IS 456:2000 limit of  $H/250 = 72.8$  mm

The comparative analysis demonstrates significant advantages of steel-concrete composite construction for multilevel parking structures:

**Displacement Control:** The composite structure shows 12% less displacement at the top storey compared to RCC (14.1 mm vs 16 mm). This reduced displacement indicates higher lateral stiffness, which is crucial for buildings in seismic zones. The superior performance can be attributed to the high strength-to-weight ratio of steel combined with the compressive strength of concrete, resulting in more efficient structural sections.

**Drift Management:** The composite structure exhibits lower storey drifts across all levels, with particular improvement at upper storeys. This is beneficial for:

- Reducing non-structural damage during seismic events
- Improving occupant comfort
- Maintaining serviceability of parking operations

### Protecting vehicle safety

**Acceleration Response:** While static acceleration participation ratios are comparable, dynamic acceleration participation is lower for composite structures. This suggests that composite structures distribute dynamic forces more effectively through their improved stiffness characteristics.

**Time Period Characteristics:** The shorter fundamental time periods of composite structures indicate:

- Higher structural stiffness
- Reduced susceptibility to resonance with seismic waves
- Better performance under dynamic loading conditions

## 5. Conclusion

Based on the detailed performance analysis of parking structures under dynamic loading, the following conclusions are drawn:

**Structural Superiority:** The maximum displacement values are lower in steel-concrete composite structure (14.1 mm) compared to RCC (16 mm), indicating that composite structures have higher stiffness and better resistance to lateral loads.

**Drift Control:** As the stiffness of composite members is higher, the storey drifts of composite structure are comparatively less than RCC parking structure, with both within permissible limits of 0.004H as per IS 1893(Part 1):2016, Clause 7.11.1.

**Code Compliance:** The maximum storey displacement obtained from analysis is well within the IS 456:2000 limit of H/250 (72.8 mm) for both structures, confirming their safety.

**Acceleration Response:** Static and dynamic acceleration are lower for composite parking structure than RCC, indicating better dynamic performance.

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