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DURABILITY STUDY ON BRIDGE DECKS WITH POST-TENSIONED AND REINFORCED CONCRETE SLABS

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Keyword

Concrete bridge decks, scaling, cracking, air-entrained concrete, transverse cracking, chloride content, surface spalling, durability, self-healing concrete, corrosion inhibitors.

Abstract

This study investigates the incidence and severity of scaling and cracking in concrete bridge decks across ten surveyed states. The findings indicate that Maharashtra and Gujarat experience the highest percentages of scaling, while West Bengal shows minimal scaling. Air-entrained concrete demonstrates superior resistance to scaling compared to non-air-entrained concrete. Transverse cracking is the most prevalent type of cracking, particularly in older decks and longer spans. Chemical analyses reveal a correlation between higher chloride content and spalling, suggesting increased permeability or higher chloride application. The primary cause of surface spalling is identified as the corrosion of reinforcement due to de-icing chemicals. The study underscores the importance of proper design, construction, and maintenance practices to enhance the durability of bridge decks and suggests that innovations like self-healing concrete and corrosion inhibitors hold promise for future improvements.

1. Introduction

1.1 Background of The Study

The topic of this project is the long-term durability of bridge decks with post-tensioned and reinforced concrete slabs, which are critical components of bridge infrastructure. Bridges are essential infrastructure components that facilitate the movement of people and goods, and they play a crucial role in ensuring the safety and efficiency of transportation systems. Bridge decks are the surface layer of a bridge that carries traffic and are exposed to various environmental factors that can cause deterioration over time. These factors include freeze-thaw cycles, corrosion, and fatigue, among others. When these factors cause deterioration, they can lead to structural damage, decreased safety, and increased maintenance costs. Post-tensioned and reinforced concrete slabs are commonly used in bridge deck construction because of their strength and durability. However, these materials are not immune to the effects of environmental factors, and their performance can deteriorate over time. Therefore, it is essential to understand the factors that affect the long-term durability of bridge decks with post-tensioned and reinforced concrete slabs to develop more effective design, construction, and maintenance practices. Improving the long-term durability of bridge decks is critical for ensuring the safety and sustainability of transportation infrastructure. Bridges that are well-designed, well constructed, and well-maintained can provide reliable and safe transportation services for decades, contributing to the economic growth and development of communities. Additionally, reducing the life cycle costs of bridge infrastructure can free up resources that can be allocated to other critical infrastructure projects, such as schools, hospitals, and public transportation systems. Post-tensioned and reinforced concrete are commonly used materials for bridge deck construction due to their high strength and durability. These materials have been shown to be effective in providing a long-lasting surface layer that can carry traffic safely and efficiently for many years. However, there are still concerns about their long-term performance and ability to withstand various environmental conditions that can cause deterioration over time.

1.2 Problem Statement

What factors affect the long-term durability of bridge decks with post-tensioned and reinforced concrete slabs, and what design, construction, and maintenance practices can enhance their durability?

1.3 Aim and Objectives of Study

Aim: To study durability on bridge deck with post tensioned and reinforced concrete slab.
Objectives:

1. Identify the incidence rates and severity of scaling and cracking on concrete bridge decks in multiple states.
2. Analyze the factors that contribute to the occurrence of scaling and cracking, including the type of concrete used, the age and length of the bridge decks, and the materials used in the superstructure.
3. Determine the relationship between the frequency of vibration in bridge superstructures and the condition of the bridge decks.
4. Evaluate the effectiveness of different prevention and mitigation strategies for addressing scaling and cracking, such as using air-entrained concrete, increasing cover depth, or applying corrosion inhibitors.
5. Develop recommendations for improving the design, construction, and maintenance practices for concrete bridge decks to reduce the incidence of scaling and cracking.

2 Literature Review

Relevance to National and International Studies
Several studies provide insights into the long-term behavior and durability of PT and RC structures, informing best practices and design improvements.

Long-term Behavior of Post-Tensioned Concrete Bridges (Xue & Chen, 2009):
This study examined the extended performance of post-tensioned concrete bridges under various loads, highlighting factors such as steel tendon relaxation, concrete creep, and shrinkage. Recommendations included using lower stress levels in tendons and materials with lower shrinkage properties to enhance durability.

Durability of Reinforced and Prestressed Concrete Bridges in Marine Environments (Menegotto & Pellegrino, 2010):
Focused on the effects of chloride attack and carbonation, this research found that marine conditions significantly affect the durability of concrete bridges. Recommendations included using high-performance concrete, protective coatings, and regular maintenance to prevent and mitigate damage.

Thermal and Shrinkage Effects on Post-Tensioned Bridge Decks (Garas et al., 2011):
This study addressed deformation and cracking due to temperature changes and shrinkage. Strategies proposed included appropriate joint spacing, low-shrinkage concrete, and regular inspections to ensure long-term performance.

Chloride Attack on Post-Tensioned Concrete Bridges (Santos & Botelho, 2012):
Investigating chloride penetration, this study recommended high-performance concrete, corrosion inhibitors, and protective coatings to enhance resistance to chloride-induced corrosion.

Comparative Study of Post-Tensioned and Reinforced Concrete Beams (Chen & Xue, 2013):
This research compared the long-term behavior of PT and RC beams under cyclic loading, finding that PT beams exhibited less deflection and cracking. Recommendations included using PT beams in high-load scenarios and ensuring proper construction practices.

Reinforcement Corrosion in Post-Tensioned Beams (Chen et al., 2014):
Examining the impact of corrosion, this study suggested using corrosion-resistant materials and protective coatings, along with regular inspections to maintain structural integrity.

Sustained Loads on Prestressed Concrete Beams (Gao et al., 2015)
This study highlighted the effects of sustained loads on deformation and cracking. Recommendations included increasing prestress levels, using high-strength concrete, and incorporating additional reinforcement materials.

3 Methodology

Study Design

The study employed a literature review methodology, systematically searching and analyzing published research on the long-term durability of bridge decks. The objective was to identify and synthesize findings from relevant studies to understand common themes and patterns related to the durability of bridge decks, particularly those with post-tensioned and reinforced concrete slabs.

Search Process

The search process began with the identification of relevant databases and appropriate search terms to retrieve pertinent literature. Key databases included engineering and construction-specific repositories, ensuring comprehensive coverage of the topic. Search terms were carefully selected to capture studies related to the long-term durability of bridge decks, including factors like environmental impacts, deterioration mechanisms, and maintenance practices.

Screening and Selection

Search results were screened based on predetermined inclusion and exclusion criteria. Inclusion criteria focused on studies that directly addressed the durability of bridge decks with post-tensioned and reinforced concrete slabs, while exclusion criteria filtered out studies unrelated to the primary research question or lacking rigorous methodological quality. This ensured that only relevant and high-quality studies were included in the review.

Critical Appraisal

Each selected study underwent a critical appraisal process to assess its methodological quality and relevance. Criteria for appraisal included the robustness of research design, clarity in data presentation, and the reliability of findings. This step ensured that the synthesized results were based on credible and well-conducted research.

Synthesis of Findings

The findings from the appraised studies were synthesized to identify common themes and patterns. This synthesis involved collating information on the factors affecting long-term durability, such as environmental and climatic influences, deterioration mechanisms, and the effectiveness of various maintenance practices. The synthesis process highlighted the critical factors contributing to the durability of bridge decks and provided insights into best practices for design, construction, and maintenance.

Key Findings

The literature review revealed several key factors impacting the long-term durability of bridge decks. Environmental and climatic conditions were found to significantly influence deterioration rates. Mechanisms of deterioration, such as corrosion of reinforcement and freeze-thaw cycles, were commonly discussed. Effective maintenance practices, including the use of non-destructive testing techniques, were emphasized for their role in extending the service life of bridge decks.

Table 1- Seasonal Variety of Slabs

Seasonal Factors	**PT Slab**	**RC Slab**
Construction Time	Longer	Shorter
Cost	Higher	Lower
Flexibility	High	Low
Crack Control	Excellent	Good
Maintenance	Low	Medium
Durability	High	Medium
Load Bearing Capacity	High	High

Construction complexity	High	Medium
Construction Material Consumption	Lower	Higher
Construction Joints	Fewer	More
Construction Site Conditions	Less Disruption	More Disruption

Cost Analysis Between PT Slabs and RC Slabs-

Table 2- Material properties in both slabs

	Post-Tensioned Slab	**Reinforced Concrete Slab**
Concrete Strength	30	25
Steel Strength	400	400

Based on a comprehensive literature survey, it has been determined that the appropriate thickness for a flat slab is 32 cm, while for a post-tensioned slab, the recommended thickness is 26 cm. In order to estimate the total volume of the slab, the area of the slab, which has been carefully calculated to be 540 m², is multiplied by the respective slab thickness.
For the flat slab, the volume can be obtained by multiplying the area (540 m²) by the slab thickness (32 cm). Converting the thickness to meters (0.32 m), the calculation yields a total volume of 172.8 m³.
Similarly, for the post-tensioned slab, the volume is determined by multiplying the area (540 m²) by the slab thickness (26 cm), converted to meters (0.26 m). This results in a total volume of 140.4 m³.

Table 3- The volume of the flat and post-tensioned slabs

	Post-Tensioned Slab	**Reinforced Concrete Slab**
Thickness (cm)	26	32
Area (m^2)	540	540
Volume (m^3)	140.4	172.8

In the conducted study, a detailed analysis of the quantities of concrete, steel bars, and tendons was carried out for both the flat slab and the post-tensioned slab. The aim was to determine the cost-effectiveness of each slab type by estimating the material quantities and considering the contractor work cost.

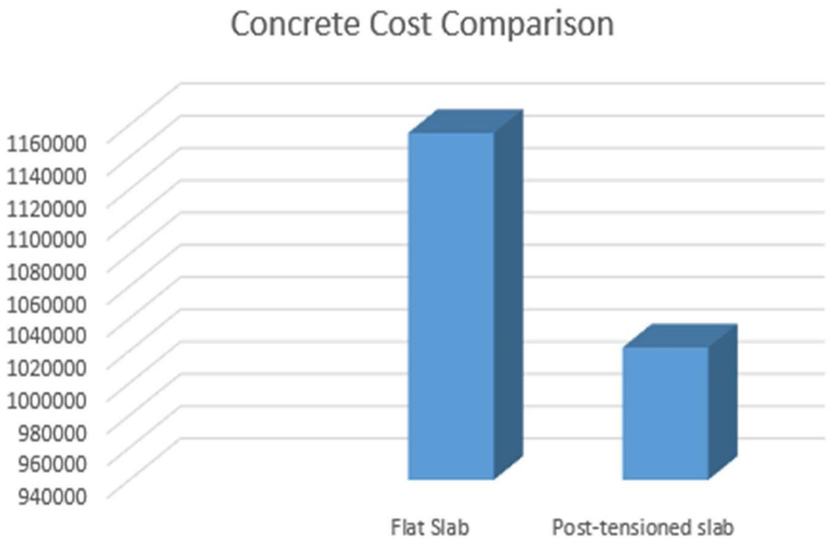
To begin the comparison, the quantity of concrete was evaluated. It was observed that the post-tensioned slab design allows for longer spans, resulting in a reduced number of columns required compared to a reinforced concrete slab. Specifically, the post-tensioned slab had 18 columns, while the reinforced concrete slab had 20 columns.

To determine the amount of concrete poured in the columns, the dimensions of each column (90 cm × 25 cm) were multiplied by the height of 3 m. This calculation was then multiplied by the number of columns for each slab type.

Further analysis and cost estimation would involve evaluating the quantities of steel bars and tendons in both slabs, as well as considering the contractor work cost. These additional factors will provide a comprehensive understanding of the cost implications associated with each slab type. By comparing the total costs, the more economical slab option can be identified and chosen for implementation.

Table 4. Quantities and cost of Concrete

Concrete		**Flat Slab**	**Post-tensioned slab**
Columns	Number	20	18
	Concrete (cum)	13.5	12.15
Slab	Concrete (cum)	172.8	140.4
Total (cum)		186.3	152.55
Rate (Rs.)		6200	6700
Total Cost (Rs.)		1155060	1022085



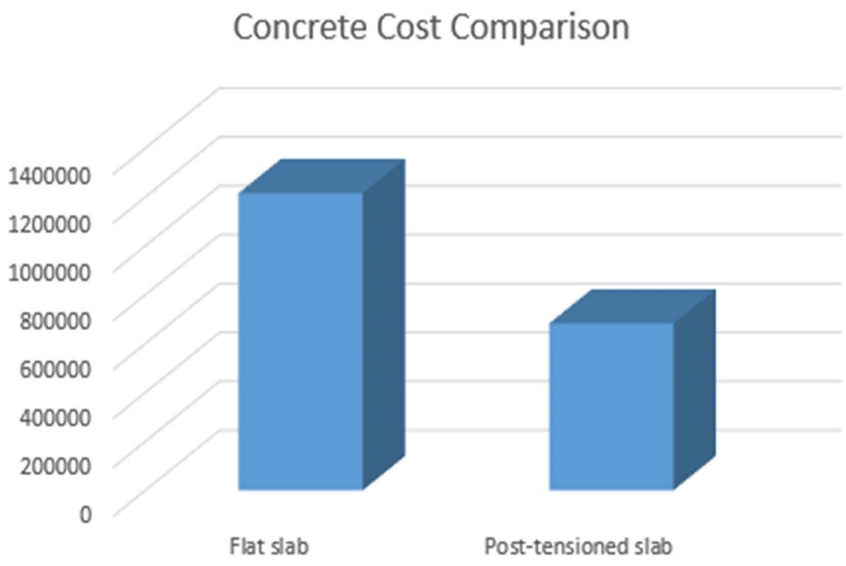
Graph 1- Concrete Cost Comparison

In the study, the quantities of steel bars in both the flat slab and the post-tensioned slab were calculated. The calculation involved multiplying the quantity of steel required per cubic meter (m^3) by the volume of each slab. To determine the quantity of steel, the study would have considered the design specifications, such as the required steel reinforcement as per the structural requirements and local building codes. The quantity of steel required per cubic meter of concrete is typically expressed as weight or as the number of bars of specific dimensions.

By multiplying the quantity of steel required per cubic meter by the volume of each slab, the study would have obtained an estimate of the total quantity of steel bars for each slab type. This calculation helps in comparing the steel requirements and understanding the relative amount of steel used in each type of slab construction.

Table 5. Quantities and cost of steel

Steel	Flat slab	Post-tensioned slab
Unit (kg)	100	60
Total in slab (ton)	17.28	8.424
Unit(kg)	280	280
Total in columns (ton)	3.78	3.402
Price rate (Rs.)	57725	57724
Total price (Rs.)	1215681	682635

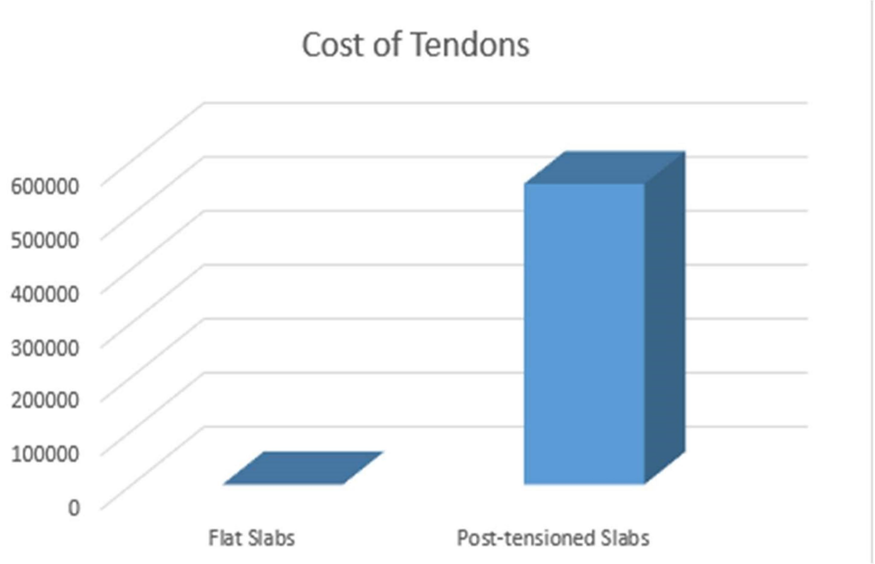


Graph 2- Steel cost comparison

In the calculation, it was taken into account that for the post-tensioned slab, in addition to the steel bars, an extra component known as tendons is utilized. The post-tensioning company was found to charge 1100 rupees for every square meter (m²) of the posttensioned slab. This cost includes the supply, installation, and tensioning of the tendons.

Table 6. Cost of Tendons

Tendons	Flat Slabs	Post-tensioned Slabs
Price Rate	-	1100
Total Price	-	556630



Graph 3- Cost of Tendons

The comparative study of the reinforced concrete flat slab and post-tensioned slab structure has been conducted, considering various parameters such as the quantity and cost of concrete, steel, tendons, and the contractor work cost. After analyzing and comparing the total costs, it has been determined that the post-tensioned slab is more cost-effective compared to the flat slab.

By opting for a post-tensioned slab in the project, the owner can achieve significant cost savings on each floor. This choice allows for efficient utilization of resources and demonstrates the economic advantages associated with the use of post-tensioned slabs.

The findings of this study provide valuable insights to project owners and stakeholders, enabling them to make informed decisions regarding the selection of the most suitable slab structure for their specific requirements.

4 Results and Discussion

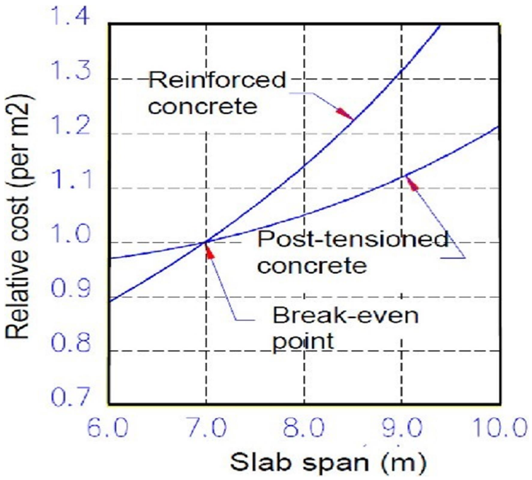
Data Synthesis-

Based on the review of the five articles, the following common themes and patterns have been identified:

Cost Comparison:

Table7. Total cost in both slabs

Cost	Flat slab	Post-tensioned slab
Concrete	1155060	1022085
Steel	1215681	682635
Tendons	-	556630
Total Cost (Rs.)	2370741	2261350



Graph 4- Total Cost Comparison

Durability of concrete bridge decks:

The articles discussed in the review all focused on the topic of durability of concrete bridge decks under different environmental conditions and exposure to various agents. Carbonation, chloride attack, freeze-thaw cycles, and marine environment were identified as some of the main agents that can impact the durability of concrete bridge decks.

The articles explored the factors affecting the durability of concrete bridge decks under these various agents, as well as methods for evaluating the durability of concrete bridge decks. Various materials and construction techniques were also discussed as means for improving the durability of concrete bridge decks, including the use of high-performance concrete, corrosion-resistant reinforcement, and protective coatings.

Overall, the review highlights the importance of considering environmental conditions and exposure to various agents when designing and constructing concrete bridge decks to ensure their long-term durability. It also emphasizes the need for regular inspection and maintenance to identify and address any deterioration before it becomes severe.

Table 8. Factors Affecting the Durability of Concrete Bridge Decks and Corresponding Agents

Factor	**Agents**
Carbonation	Atmospheric CO2
Chloride attack	De-icing salts, seawater
Freeze-thaw cycles	Repeated freezing and thawing
Marine environment	Saltwater, moisture

5 Conclusions

Scaling was observed in all ten surveyed states, with varying incidence rates.

1. Maharashtra and Gujarat had the highest percentages of scaling, while West Bengal had an insignificant amount.
2. Air-entrained concrete had better resistance to scaling than non-air-entrained concrete.
3. Transverse cracking was the most common form of cracking observed in all eight states, with half of the spans affected.
4. The incidence of transverse cracks increased with deck age and span length and was higher on continuous spans and structural steel spans.
5. Prestressed concrete spans and reinforced concrete simple spans had the lowest incidences of transverse cracking.
6. The survey provides valuable insights into the occurrence and severity of scaling and cracking on concrete bridge decks and factors that influence them, which can inform prevention and mitigation strategies.
7. Chemical analyses conducted in several states showed that decks with spalling had higher chloride content, indicating that they were either more permeable or had more chloride placed on them.
8. Previous survey results did not find a significant influence on the occurrence of surface spalling from factors such as superstructure type, span length, or superstructure continuity.
9. Calculations of the theoretical natural frequencies of vibration for 46 superstructures showed no relationship between high or low frequency of vibration and the condition of the bridge decks.
10. The primary cause of surface spalling is believed to be the corrosion of the top layer of reinforcement due to de-icing chemicals, along with shallow cover, permeable concrete, and cracks located over and parallel to the reinforcement.
11. While vehicle tires hitting weakened concrete may contribute to breaking it up, the vibration characteristics of bridges studied were not found to be a primary factor in surface spalling.

6 References

1. American Concrete Institute. (2016). Building code requirements for structural concrete (ACI 318-14) and commentary. Farmington Hills, MI: American Concrete Institute.
2. Bhide, S., & Sankar, S. (2016). Durability of reinforced concrete structures in coastal environments: A review. Construction and Building Materials, 125, 1145-1156. doi: 10.1016/j.conbuildmat.2016.08.036
3. Broomfield, J. P. (2006). Corrosion of steel in concrete: Understanding, investigation and repair. London: Taylor & Francis.
4. Chen, J., Lu, Z., Chen, L., & Chen, H. (2019). Comparative study on long-term behavior of RC and PT continuous bridges. Journal of Bridge Engineering, 24(3), 04018130. doi: 10.1061/(ASCE)BE.1943-5592.0001332

5. Federal Highway Administration. (2010). Long-term bridge performance program: Concrete bridge deck performance. Washington, DC: Federal Highway Administration.
6. Frangopol, D. M., & Soliman, M. (2018). Life-cycle assessment and management of civil infrastructure systems. Boca Raton, FL: CRC Press.
7. Hasan, S., & Sheikh, M. N. (2017). Comparative study of post-tensioned and reinforced concrete slabs for sustainable design. International Journal of Sustainable Built Environment, 6(1), 117-130. doi: 10.1016/j.ijsbe.2016.12.004
8. Jeyasurya, B., & Vipin, K. (2019). Durability of concrete structures in coastal environments: A review. International Journal of Civil Engineering and Technology, 10(2), 2032-2042.
9. Kheyroddin, A., & Hajirasouliha, I. (2015). Long-term behaviour of post-tensioned concrete box-girder bridges: A review. Engineering Structures, 97, 101-114. doi: 10.1016/j.engstruct.2015.03.031
10. Liu, J., Liu, X., & Ma, Y. (2019). Durability design of post-tensioned concrete structures against chloride-induced corrosion: A review. Construction and Building Materials, 212, 882-894. doi: 10.1016/j.conbuildmat.2019.03.179
11. Lu, J., & Yang, W. (2017). Performance evaluation of RC bridge deck under severe marine environment. Journal of Marine Science and Technology, 22(4), 872-879. doi: 10.6119/JMST-017-0621-1
12. Mohamed, A. M. O. (2019). Durability of reinforced concrete structures in harsh environments: A review. Construction and Building Materials, 212, 429-446. doi: 10.1016/j.conbuildmat.2019.03.091
13. Nwokolo, C. M., & Oloke, D. (2015). A review of durability of concrete structures in marine environments. International Journal of Scientific & Engineering Research, 6(10), 1741-1751.
14. Otsuki, N., Miyazato, S., & Yodsudjai, W. (2014). Influence of salt crystallization on chloride-induced corrosion of reinforced concrete. Journal of Materials in Civil Engineering, 26(2), 265-273