COMPARATIVE STUDY ON STRUCTURAL PERFORMANCE OF UNDERPASS BRIDGE WITH SEISMIC LOADS

Mr. Om J. Gabhane[1] Dr. B. H. Shinde [2]

[1]Student M. Tech. (Structural Engg.) Dept. of Civil Engineering, G. H. Raisoni University, Amaravati, Maharashtra, India

[2]Associate Professor, Dept. of Civil Engineering, G.H.Raisoni University, Amaravati, Maharashtra, India

[1]akashgabhane29gmail.com, [2]bhushan.shinde@ghrua.edu.in

***Abstract*— Underpass bridges are essential transportation structures designed to facilitate uninterrupted traffic movement in urban and highway networks. These structures are continuously subjected to vehicular loads and are also vulnerable to seismic effects, particularly in earthquake-prone regions. The present study investigates the structural performance of reinforced concrete (RCC) box-type underpass bridges subjected to static vehicular loading and seismic loading conditions. Three-dimensional numerical models with span lengths of 5 m, 10 m, and 15 m were developed and analyzed using appropriate structural analysis software in accordance with IRC and IS 1893:2016 provisions. Parameters such as displacement, base shear, natural time period, frequency, acceleration response, and stress distribution were evaluated. Comparative analysis between pier bridge and box bridge configurations was also carried out under seismic loading conditions. The results indicate that the box bridge configuration provides superior seismic resistance with approximately 9.44% lower displacement compared to the pier bridge. The 10 m span bridge demonstrated the most balanced structural performance with minimum displacement, moderate base shear, and stable dynamic characteristics. The study concludes that moderate-span RCC box-type underpass bridges are structurally efficient and suitable for seismic-prone regions.**

Keywords: Underpass Bridge, Box Bridge, Seismic Analysis, Vehicular Load, Dynamic Analysis, Base Shear, RCC Structure, Soil-Structure Interaction.

I. INTRODUCTION

Bridges are among the most important components of transportation infrastructure and play a vital role in the economic, social, and industrial development of a nation. They provide safe and uninterrupted movement of people, goods, and services across physical obstacles such as rivers, valleys, railway tracks, and highways. With the rapid growth of urbanization, industrialization, and population, the demand for efficient transportation systems has increased significantly. As a result, modern highway and urban transportation networks require advanced bridge systems capable of handling heavy traffic volumes while ensuring safety, durability, and serviceability.

Among the various bridge systems, underpass bridges have become an essential part of present-day transportation infrastructure. Underpass bridges are generally constructed to separate traffic movement at busy intersections, railway crossings, and highway junctions where uninterrupted flow of vehicles is necessary. These structures help in reducing traffic congestion, minimizing delays, and improving overall transportation efficiency. Underpasses are particularly beneficial in densely populated urban regions where conventional at-grade crossings often lead to severe traffic interruptions and accidents.

Reinforced Cement Concrete (RCC) box-type underpass structures are commonly adopted because of their structural rigidity, durability, ease of construction, and ability to resist heavy loads and lateral earth pressure. The closed box configuration provides better load distribution and higher torsional stiffness compared to conventional pier-supported bridge systems. In addition, RCC box structures require comparatively lower maintenance and exhibit better performance under underground and partially buried conditions. Due to these advantages, box-type underpass bridges are increasingly used in highways, railways, pedestrian crossings, and urban infrastructure projects.

However, underpass bridges are subjected to various types of loading conditions throughout their service life. These include dead loads due to self-weight, vehicular live loads, braking forces, impact loads, lateral earth pressure, and groundwater pressure. In seismic-prone regions, earthquake-induced dynamic forces also become critical factors affecting the safety and stability of the structure. Earthquake loading can produce significant stresses, deformation, vibration, and displacement in the bridge system, especially in underground and semi-underground structures where soil–structure interaction plays an important role.

Traditionally, bridge design practices often evaluate vehicular loads and seismic loads separately. Although such an approach simplifies analysis and design procedures, it may not accurately represent the actual behavior of underpass structures under realistic service conditions. In practical situations, bridges may experience combined effects of static vehicular loading and dynamic seismic loading simultaneously or sequentially. Therefore, a comprehensive evaluation considering both loading conditions is essential for ensuring structural safety, serviceability, and long-term durability.

Another important aspect influencing the behavior of underpass bridges is soil–structure interaction (SSI). Since box-type underpass structures are generally surrounded by soil, the interaction between the surrounding soil mass and structural components significantly affects load transfer mechanisms, stress distribution, stiffness, and deformation characteristics. Lateral earth pressure acting on sidewalls and the confinement effect of soil can alter the seismic response of the structure considerably. Neglecting these effects may lead to inaccurate estimation of internal forces and structural response.

In recent years, several researchers have studied the structural behavior of bridges under static and seismic loading conditions. However, most of the available studies are focused on conventional bridge systems, while comparatively fewer investigations have been conducted on RCC box-type underpass bridges. Furthermore, limited research is available regarding the comparative performance of underpass bridges with varying span lengths under combined vehicular and earthquake loading conditions. Understanding the influence of span variation on displacement, base shear, natural time period, acceleration response, and stress distribution is essential for achieving an economical and structurally efficient design.

Therefore, the present study aims to investigate the comparative structural performance of RCC underpass bridge systems subjected to vehicular and seismic loads. Three-dimensional numerical models of underpass bridges with span lengths of 5 m, 10 m, and 15 m are developed and analyzed using suitable structural analysis software in accordance with IRC and IS 1893:2016 codal provisions. The study evaluates important structural parameters such as displacement, base shear, natural frequency, time period, acceleration response, and stress distribution under static and dynamic loading conditions.

In addition, a comparative analysis between pier bridge and box bridge configurations is carried out to identify the most effective structural system under seismic loading. The outcomes of this research are expected to provide useful insights for the safe and economical design of underpass bridge structures, particularly in seismic-prone regions.

II. OBJECTIVES OF THE STUDY

The major objectives of the study are:

1. To model and analyse RCC underpass bridge structures using suitable structural analysis software.
2. To evaluate the structural behaviour under vehicular loading conditions.
3. To investigate the seismic performance of underpass bridges under earthquake loads.
4. To compare the response of different span lengths under static and dynamic loading.
5. To compare the seismic performance of pier bridge and box bridge configurations.
6. To determine the most structurally efficient underpass bridge configuration.

III. LITERATURE REVIEW

Several researchers have investigated the behaviour of underpass bridges and box culvert structures under static and seismic loading conditions.

Piyush Tiwari et al. studied the analysis and design of box underpass bridges and highlighted the advantages of box-type structures in urban transportation systems. Baishun Xu et al. compared the seismic vulnerability of steel–concrete composite girder bridges and reinforced concrete girder bridges and concluded that composite girders exhibit improved seismic resistance.

Hamayoon Kheradi et al. performed shaking table tests to evaluate seismic enhancement methods for box culverts. Their study demonstrated the importance of soil–structure interaction in underground structures. Raghava Kumar et al. conducted finite element analysis on skew underpass box structures and observed that three-dimensional analysis provides more accurate results than two-dimensional frame analysis.

Previous studies primarily focused on conventional bridge systems and simplified analytical models. Limited research has been carried out on comparative seismic performance of box-type underpass bridges with varying span lengths under combined loading conditions.

IV. RESEARCH GAP

Previous studies on underpass bridges have mainly focused on conventional bridge systems and static loading conditions. Limited research is available on RCC box-type underpass bridges subjected to combined vehicular and seismic loads. In many cases, the influence of soil–structure interaction and lateral earth pressure has been neglected or simplified, despite their significant effect on the structural behaviour of underpass structures.

Additionally, only a few studies have compared the performance of different span lengths under dynamic loading conditions. Parameters such as displacement, base shear, time period, acceleration response, and stress distribution for varying spans have not been thoroughly investigated. Most earlier research also relied on simplified two-dimensional analysis rather than realistic three-dimensional modelling.

Therefore, the present study aims to fill these gaps by carrying out a comprehensive comparative analysis of RCC underpass bridges with different span lengths under vehicular and seismic loading conditions using three-dimensional numerical modelling and relevant codal provisions.

V. METHODOLOGY

The present study focuses on the comparative structural performance evaluation of RCC box-type underpass bridges subjected to vehicular and seismic loading conditions. A systematic methodology was adopted involving modelling, loading, analysis, and interpretation of results using suitable structural analysis software and codal provisions. The methodology primarily includes structural configuration, loading conditions, and analysis procedures for different span lengths of underpass bridges.

5.1 STRUCTURAL CONFIGURATION

In the present research, Reinforced Cement Concrete (RCC) box-type underpass bridge structures were considered for analysis. Box-type underpass bridges were selected because of their high rigidity, better load distribution capacity, and suitability for underground and highway crossing applications. The closed structural configuration of the box section provides improved resistance against lateral earth pressure and seismic forces compared to conventional bridge systems.

To study the effect of span variation on structural behaviour, three different bridge models were developed with span lengths of:

- 5 m
- 10 m
- 15 m

These span lengths were selected to represent short, medium, and comparatively longer underpass bridge configurations commonly adopted in transportation infrastructure projects.

A. Structural Components

Each bridge model consists of the following major structural elements:

1) Top Slab

The top slab acts as the primary load-carrying component subjected to vehicular loads, wearing course loads, and earth fill loads. It transfers the applied loads to the sidewalls and contributes significantly to the stiffness of the structure.

2) Bottom Slab

The bottom slab acts as the foundation element of the box structure and distributes loads safely to the supporting soil. It also resists uplift pressure and contributes to overall structural stability.

3) Side Walls

The side walls resist lateral earth pressure and transfer vertical and horizontal loads between the top slab and bottom slab. During seismic loading, the sidewalls play a major role in resisting dynamic forces and maintaining structural integrity.

B. Material Properties

The material properties adopted for modelling and analysis were based on standard construction practices and codal recommendations.

1) Concrete

- Grade of Concrete: **M25**
- Characteristic compressive strength: **25 MPa**

M25 grade concrete was selected because it is commonly used in RCC bridge construction due to its adequate strength, durability, and workability.

2) Reinforcement Steel

- Grade of Reinforcement Steel: **Fe500**
- Yield strength: **500 MPa**

Fe500 steel was considered for reinforcement because of its higher tensile strength and better ductility under loading conditions.

C. Geometric Details

The geometric dimensions of the underpass bridge models were adopted based on standard underpass requirements and practical design considerations.

Parameter	**Value**
Overall width of underpass	8.74 m
Vertical clearance	3.84 m
Internal width	3.06 m to 4.74 m

The dimensions were maintained consistently for all models except the span length, which was varied to study its influence on structural behaviour.

5.2 LOADING CONDITIONS

The underpass bridge structures were analysed under different loading conditions in accordance with relevant IRC and IS code provisions. The loads considered in the study represent realistic service and seismic conditions experienced by underpass structures.

D. Dead Load (DL)

Dead load consists of the self-weight of all structural components including:

- Top slab
- Bottom slab
- Side walls
- Wearing course

The self-weight of RCC components was automatically calculated by the software based on material density. The wearing course load was applied according to IRC recommendations.

Dead load acts permanently on the structure throughout its service life and significantly influences the overall seismic weight of the bridge.

E. Live Load (LL)

Vehicular loading was considered as per IRC loading provisions for highway bridges. The live load includes:

- Moving vehicular loads
- Uniformly distributed loads
- Braking and traction forces

These loads simulate actual traffic conditions acting on the bridge deck. Vehicular loading plays a major role in producing bending moments, shear forces, and displacement in the structure.

F. Earth Pressure

Since the underpass bridge is partially embedded within soil, lateral earth pressure acting on the side walls was considered in the analysis.

The active earth pressure was calculated using Rankine's earth pressure theory considering:

- Unit weight of soil
- Angle of internal friction
- Height of retained soil

Earth pressure significantly affects the behaviour of sidewalls and contributes to the overall load acting on the structure.

G. Seismic Load

Earthquake loading was applied according to IS 1893:2016 using the equivalent static method. Seismic analysis was carried out considering:

- Seismic Zone III
- Importance factor
- Response reduction factor
- Spectral acceleration coefficient

The seismic load generates inertia forces in the structure due to ground motion. These forces influence displacement, base shear, acceleration response, and stress distribution in the bridge system.

5.3 ANALYSIS PROCEDURE

The structural analysis was carried out using three-dimensional numerical modelling techniques in suitable structural analysis software. Three-dimensional modelling was adopted to accurately represent the behaviour of RCC box-type underpass bridges under combined loading conditions.

The modelling process involved:

1. Development of 3D geometry for each span length.
2. Assignment of material properties and sectional dimensions.
3. Application of boundary conditions and support restraints.
4. Application of dead load, live load, earth pressure, and seismic loads.
5. Static and dynamic analysis of the structure.

H. Static Analysis

Static analysis was performed to evaluate the structural response under dead load, live load, and earth pressure conditions. The following parameters were studied:

1) Displacement

Maximum displacement of the bridge structure was evaluated to study stiffness and deformation behaviour.

2) Base Shear

Base shear was calculated to determine the total lateral seismic force acting on the structure.

3) Stress Distribution

Stress concentration in slabs and sidewalls was analysed to identify critical structural regions.

I. Dynamic Analysis

Dynamic analysis was conducted to study the seismic behaviour and vibration characteristics of the underpass bridges.

The following parameters were evaluated:

1) Natural Time Period

The natural time period of different vibration modes was determined to understand the dynamic characteristics of the structure.

2) Frequency

Natural frequency values were calculated to evaluate structural stiffness and vibration response.

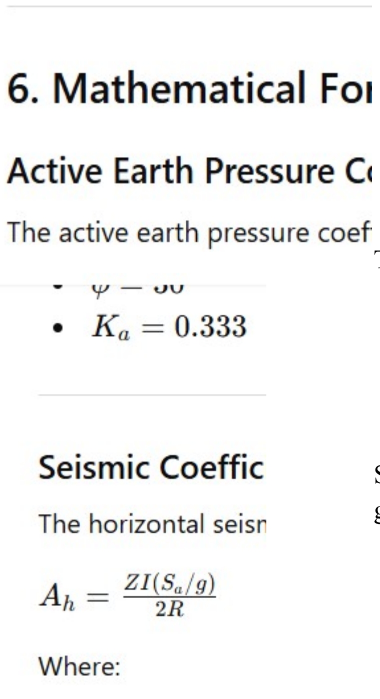
3) Acceleration Response

Time-history acceleration response was studied to examine the effect of seismic excitation on the bridge models.

4) Maximum Stress

Maximum absolute stress developed during dynamic loading was evaluated to assess structural safety under earthquake conditions.

VI. MATHEMATICAL FORMULATION



6. Mathematical Fo

Active Earth Pressure C

The active earth pressure coef

- $\varphi = 30$
- $K_a = 0.333$

Seismic Coeffic

The horizontal seisr

$$A_h = \frac{ZI(S_a/g)}{2R}$$

Where:

VII. RESULTS AND DISCUSSION

7.1 Comparative Seismic Performance

A comparative analysis between pier bridge and box bridge configurations showed:

Bridge Type	**Maximum Displacement (mm)**
Pier Bridge	3.93
Box Bridge	3.559

The box bridge exhibited approximately 9.44% lower displacement, indicating higher rigidity and improved seismic resistance.

7.2 Base Shear Analysis

Span Length	Total Weight (kN)	Base Shear (kN)
5 m	2921	87.63
10 m	5801	116.02
15 m	8682	130.23

The base shear increased with increase in span length due to higher seismic mass and flexibility.

7.3 Displacement Analysis

Span Length	Maximum Displacement (mm)
5 m	3.559
10 m	2.89
15 m	2.93

The 10 m span bridge showed minimum displacement and better structural stability.

7.4 Dynamic Analysis

1) Natural Time Period

Mode	5 m Span	10 m Span	15 m Span
1	0.06	0.052	0.052
2	0.052	0.049	0.05
3	0.047	0.047	0.047

The time period decreased with increased stiffness.

2) Frequency Analysis

Mode	5 m Span (Hz)	10 m Span (Hz)	15 m Span (Hz)
1	16.68	19.148	19.347
2	19.141	20.351	19.932

Shorter span bridges exhibited higher frequencies due to greater stiffness.

3) Time vs Acceleration

Span Length	Acceleration
5 m	31.4
10 m	24.7
15 m	24.9

The 5 m span bridge experienced the highest acceleration response.

4) Maximum Absolute Stress

Span Length	Stress (N/mm²)
5 m	0.0328563

10 m	0.028527
15 m	0.0282977

Longer span bridges exhibited more uniform stress distribution.

VIII. CONCLUSION

The present study evaluated the structural performance of RCC underpass bridge systems subjected to vehicular and seismic loading conditions.
The following conclusions were drawn:

1. Box bridge configurations showed superior seismic performance compared to pier bridges.
2. The box bridge exhibited approximately 9.44% lower displacement under earthquake loading.
3. Base shear increased with increase in span length due to higher structural mass.
4. Shorter span bridges possessed higher stiffness but experienced greater acceleration and stress concentration.
5. The 10 m span bridge demonstrated the most balanced structural behaviour with minimum displacement and stable dynamic response.
6. All bridge models remained structurally safe under the considered loading conditions.
7. Moderate-span RCC box-type underpass bridges are recommended for seismic-prone regions because of their improved rigidity and structural efficiency.

IX. FUTURE SCOPE

The following areas may be considered for future research:

- Nonlinear dynamic analysis under real earthquake records.
- Detailed soil–structure interaction analysis.
- Use of prestressed concrete and composite materials.
- Experimental validation using shake table testing.
- Fatigue and durability assessment under repeated loading.

REFRENCES

1. Piyush Tiwari et.al. “Analysis and Design of Box Underpass Bridge Using Software” International Journal of Trend in Scientific Research and Development, Volume 5 Issue 6, (2021)
2. Baishun Xu et. al. “Comparative Study on the Seismic Vulnerability of Continuous Bridges with Steel–Concrete Composite Girder and Reinforced Concrete Girder” MDPI, 2024
3. Halil İbrahim Yumrutaş et.al. “Comparison of Overpass / Underpass in the Light of Various Parameters: Karabuk - Safranbolu Case Study” Araştırma Makalesi / Research Article 2021
4. Mr. Vishwasu Gopalraje et.al. “Pre-Cast RCC Underpass box structure for Railway Track Crossings” International Advanced Research Journal in Science, Engineering and Technology, 2022
5. Ye Dan et. al. “Research on the impact of underground box culvert underpass construction on the pier of intercity railroad bridge” Academic Journal of Architecture and Geotechnical Engineering, 2024
6. Hamayoon Kheradi et. al. “1-g shaking table tests on seismic enhancement of existing box culvert with partial ground-improvement method and its 2D dynamic simulation” Science Direct 19 June 2018
7. Paulo Rui Anciaes et. al. “Estimating preferences for different types of pedestrian crossing facilities” Transportation Research Part F 52 (2018) 222–237 22 December 2017
8. M. Bhardwaja et. al. “Differential use of highway underpasses by bats” © 2017 Elsevier Ltd. 22 May 2017
9. Yasuo Sawamura et.al. “Deformation behavior and acting earth pressure of three-hinge precast arch culvert in construction process” Elsevier Ltd. 2 November 2018
10. Manuel F. Báez H et.al. “A vibration prediction model for culvert-type railroad underpasses” Elsevier Ltd. 6 June 2018
11. Mohammad Afifipour et.al. “Interaction of twin tunnels and shallow foundation at Zand underpass, Shiraz metro, Iran” Elsevier Ltd. 3 December 2010
12. Juan D. Delgado et.al. “Is vertebrate mortality correlated to potential permeability by underpasses along low-traffic roads?” Elsevier Ltd. 14 May 2018
13. Zhongxiang Feng et.al. “Effect of longitudinal slope of urban underpass tunnels on drivers’ heart rate and speed: A study based on a real vehicle experiment” Elsevier Ltd. 16 August 2018
14. Vasileios Grigoriou et.al. “Monitoring-based safety verification at the Ultimate Limit State of fracture of the RC slab of a short span railway underpass” 25 January 2016

15. Marcel P. Huijser et.al. “Effectiveness of short sections of wildlife fencing and crossing structures along highways in reducing wild life–vehicle collisions and providing safe crossing opportunities for large mammals” 1 February 2016
16. V. Raghava Kumar et.al. “Finite Element Analysis of Skew Box Underpass Bridge” Indian Highways, Volume 44, Issue Number 2, (2016)
17. Jong-Kook Jung et. al. “A comparison of diversity and composition of carabid beetles between Overpasses and underpasses in fragmented forest areas” 18 September 2017
18. Alexis Laforge et. al. “Landscape context matters for attractiveness and effective use of road Underpasses by bats” 15 July 2019
19. Shao-Ming Liao et. al. “The planning and construction of a large underpass crossing urban expressway in Shanghai: An exemplary solution to the traffic congestions at dead end roads” 7 July 2018
20. Mathilde L. Tissier et. al. “An anti-predation device to facilitate and secure the crossing of small mammals in motorway wildlife underpasses. (II) Validation with the European hamster under semi-natural conditions” 19 October 2018