COMPARATIVE STUDY OF DYNAMIC BEHAVIOR OF PRE-ENGINEERED AND CONVENTIONAL STEEL INDUSTRIAL STRUCTURE

Mr. Abdul Zareef Abdul Zarrar[1] Ishant Dahat[2]

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

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

[1]abdulzareef1234.ss@gmail.com

***Abstract*— Transportation infrastructure plays a significant role in the economic and social development of a country. Underpass bridges are essential components of modern transportation systems as they facilitate uninterrupted traffic movement at road intersections, railway crossings, and highways. Due to increasing urbanization and traffic density, RCC box-type underpass bridges are increasingly preferred because of their rigidity, durability, and ability to resist heavy loading conditions.**

The present study investigates the structural behaviour of RCC box-type underpass bridges subjected to vehicular and seismic loading conditions. Three-dimensional numerical models with span lengths of 5 m, 10 m, and 15 m were developed and analysed using structural analysis software in accordance with IRC and IS 1893:2016 provisions. Static and dynamic analyses were carried out to evaluate displacement, base shear, natural time period, frequency response, acceleration response, and maximum stress.

The study also compares the seismic performance of conventional pier-supported bridge systems and RCC box bridge systems. Results indicate that the RCC box bridge configuration exhibits improved rigidity and better seismic resistance with lower displacement response. The 10 m span bridge demonstrated optimum structural performance with minimum displacement and stable dynamic behaviour. The study concludes that moderate-span RCC box-type underpass bridges are structurally efficient and suitable for seismic-prone regions.

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

I. INTRODUCTION

Bridges are among the most essential infrastructural components of modern transportation systems and play a crucial role in the economic, industrial, and social development of a nation. They facilitate the safe and efficient movement of people, vehicles, and goods across physical obstacles such as rivers, valleys, railway lines, and highways. A well-developed bridge network significantly improves transportation efficiency by reducing travel time, minimizing traffic congestion, lowering transportation costs, and enhancing regional connectivity. With rapid urbanization, industrial expansion, and population growth, the demand for advanced transportation infrastructure has increased considerably in recent decades.

In rapidly developing urban areas, conventional at-grade intersections often become inadequate because of increasing traffic density and limited land availability. Traffic congestion at railway crossings, road intersections, and highway junctions leads to delays, fuel wastage, environmental pollution, and increased accident risk. To overcome these issues, grade separation structures such as flyovers, overpasses, and underpass bridges are widely adopted in modern transportation planning. Among these, underpass bridges have become one of the most effective solutions for maintaining uninterrupted traffic flow while improving transportation safety and operational efficiency.

Underpass bridges are commonly constructed beneath highways, railway tracks, or urban road networks to allow traffic movement below existing transportation corridors. These structures eliminate conflicts between intersecting traffic streams and significantly improve road safety by reducing the possibility of collisions at crossings. Underpasses are especially beneficial in congested urban regions where expansion of road width is difficult due to limited space and surrounding infrastructure. In addition, underpass systems improve traffic management and support continuous transportation operations without disturbing existing routes.

Reinforced Cement Concrete (RCC) box-type underpass bridges are extensively used because of their high rigidity, structural stability, durability, and economical construction. The box-type configuration provides a closed structural system that efficiently distributes loads and resists bending, shear, and torsional effects. Compared to conventional pier-supported bridge systems, RCC box structures possess greater stiffness and better resistance against lateral earth pressure and surcharge loads. The rigid box action also enhances the load-carrying capacity of the structure under heavy vehicular traffic.

Another major advantage of RCC box underpass bridges is their ability to perform effectively under underground and partially buried conditions. Since these structures remain surrounded by soil, they receive additional confinement and support from the surrounding earth mass. RCC box structures also require comparatively lower maintenance and offer longer service life due to their monolithic construction and resistance to environmental deterioration. Because of these advantages, RCC box-type underpass bridges are widely used in highway projects, railway crossings, metro transportation systems, and urban infrastructure development.

Despite their advantages, underpass bridges are continuously subjected to various loading conditions throughout their service life. These include dead loads due to self-weight of structural components, vehicular live loads, impact loads, braking forces, surcharge loads, lateral earth pressure, hydrostatic pressure, and seismic loads. The combined influence of these loads significantly affects the structural behaviour, stability, and durability of the bridge system.

Among all loading conditions, seismic loading becomes one of the most critical factors in earthquake-prone regions. Earthquake-induced ground motion generates dynamic inertia forces within the structure, resulting in vibration, displacement, stress concentration, and deformation. If seismic effects are not properly considered during design, the bridge may experience cracking, excessive settlement, instability, or even structural failure. Therefore, seismic analysis is essential for ensuring the safety and serviceability of underpass bridges located in seismic zones.

Conventional bridge analysis methods often consider vehicular loads and seismic loads independently for simplification purposes. However, actual service conditions involve the combined effects of static and dynamic loads acting simultaneously or sequentially. In practical situations, underpass bridges may experience heavy vehicular traffic while also being subjected to earthquake excitation. Therefore, separate analysis of these loads may not accurately represent the actual structural behaviour of the bridge.

Another important factor influencing the performance of RCC underpass bridges is soil–structure interaction (SSI). Since underpass bridges are embedded within soil, the surrounding soil significantly affects stiffness, damping properties, load transfer mechanisms, and overall seismic response of the structure. Lateral earth pressure acting on the sidewalls and confinement effects provided by soil alter the dynamic characteristics and deformation pattern of the bridge system. Neglecting soil–structure interaction may lead to inaccurate estimation of stresses and structural response.

Several researchers have previously studied bridge behaviour under static and seismic loading conditions. However, most of the available studies are focused on conventional bridge systems and simplified analytical methods. Limited research has been conducted on RCC box-type underpass bridges subjected to combined vehicular and seismic loading conditions. Furthermore, comparative studies involving different span lengths and their influence on displacement, base shear, vibration characteristics, and stress distribution are limited in existing literature.

To address these limitations, the present study focuses on the comparative structural performance of RCC box-type underpass bridges with span lengths of 5 m, 10 m, and 15 m under vehicular and seismic loading conditions. Three-dimensional numerical models are developed using structural analysis software to accurately simulate the behaviour of the bridge systems under combined loading effects. Both static and dynamic analyses are carried out in accordance with IRC and IS 1893:2016 codal provisions.

The study evaluates important structural parameters such as displacement, base shear, natural time period, frequency response, acceleration response, and maximum stress distribution. In addition, comparative seismic analysis between conventional pier-supported bridges and RCC box bridge systems is performed to determine the most structurally efficient and stable configuration for seismic-prone regions.

The findings of this research are expected to contribute towards safer, more economical, and structurally efficient design practices for underpass bridges in modern transportation infrastructure projects.

II. OBJECTIVES OF THE STUDY

The primary objectives of the present research are:

1. To model RCC box-type underpass bridges with different span lengths using structural analysis software.
2. To evaluate the structural behaviour of underpass bridges under vehicular loading conditions.
3. To study the seismic response of underpass bridge systems under earthquake loading.
4. To compare the structural performance of bridges with span lengths of 5 m, 10 m, and 15 m.
5. To analyse parameters such as displacement, base shear, frequency, acceleration, and stress response.
6. To compare the seismic behaviour of pier-supported bridges and RCC box bridge systems.
7. To determine the most efficient and stable underpass bridge configuration for seismic-prone regions.

III. LITERATURE REVIEW

Several researchers have investigated the behaviour of bridge systems and underground structures under static and seismic loading conditions.

Piyush Tiwari et al. conducted analysis and design studies on RCC box-type underpass bridges and concluded that box structures provide better rigidity and load distribution for urban transportation systems.

Baishun Xu et al. carried out a comparative study on seismic vulnerability of steel–concrete composite girder bridges and reinforced concrete girder bridges. Their study indicated that composite systems exhibit improved seismic performance due to enhanced ductility and energy dissipation capacity.

Hamayoon Kheradi et al. performed shaking table tests on box culvert structures to study seismic enhancement techniques and observed that soil–structure interaction significantly influences structural response during earthquakes.

Raghava Kumar et al. analysed skew underpass box structures using finite element methods and concluded that three-dimensional analysis provides more accurate results compared to simplified two-dimensional methods.

Most previous studies focused mainly on conventional bridge systems or static loading conditions. Limited studies are available regarding combined vehicular and seismic loading on RCC underpass bridges with varying span lengths.

IV. RESEARCH GAP

The literature review reveals several research gaps related to RCC underpass bridge systems.

Most previous studies focused mainly on static loading conditions and conventional bridge structures. Limited research has been conducted on RCC box-type underpass bridges subjected to combined vehicular and seismic loading conditions. In practical situations, bridges experience both traffic loads and earthquake forces simultaneously or sequentially, which significantly affects structural behaviour.

Another major gap is the inadequate consideration of soil–structure interaction effects. Since underpass bridges remain surrounded by soil, lateral earth pressure and soil confinement considerably influence displacement, stress distribution, and seismic response. However, many earlier investigations neglected these effects or adopted simplified assumptions.

Comparative analysis of different span lengths under dynamic loading conditions is also limited. Parameters such as base shear, natural frequency, acceleration response, and stress concentration for varying spans have not been thoroughly investigated.

Furthermore, most earlier studies relied on simplified two-dimensional analysis methods rather than realistic three-dimensional modelling approaches.

Therefore, the present study attempts to bridge these gaps through a comprehensive comparative analysis of RCC box-type underpass bridges under vehicular and seismic loading conditions using three-dimensional numerical modelling.

V. METHODOLOGY

5.1 Structural Configuration

The present study considers RCC box-type underpass bridge structures with span lengths of:

- 5 m
- 10 m
- 15 m

These span lengths were selected to evaluate the effect of span variation on structural performance under static and dynamic loading conditions.

1) Structural Components

Each bridge model consists of:

- Top slab

- Bottom slab
- Side walls

The top slab carries vehicular loads and transfers them to the side walls. The bottom slab distributes loads safely to the supporting soil, while the side walls resist lateral earth pressure and seismic forces.

2) Material Properties

The material properties adopted for analysis are:

Material	**Property**
Concrete Grade	M25
Reinforcement Steel	Fe500

M25 grade concrete was selected due to its adequate compressive strength and durability. Fe500 reinforcement steel was adopted because of its higher tensile strength and ductility.

3) Geometric Details

Parameter	**Value**
Overall Width	8.74 m
Vertical Clearance	3.84 m
Internal Width	3.06 m – 4.74 m

5.2 Loading Conditions

The following loading conditions were considered for structural analysis.

4) Dead Load

Dead load includes self-weight of structural components such as slabs and sidewalls along with the wearing course. The self-weight was automatically calculated by the software based on material density.

5) Live Load

Vehicular loading was applied according to IRC specifications for highway bridges. These loads simulate actual traffic conditions acting on the bridge deck.

6) Earth Pressure

Lateral earth pressure acting on side walls was calculated using Rankine's earth pressure theory considering soil properties and retained height.

7) Seismic Load

Earthquake loading was applied according to IS 1893:2016 using the equivalent static method. Seismic parameters such as zone factor, importance factor, and response reduction factor were considered during analysis.

5.3 Analysis Procedure

Three-dimensional numerical models of the bridge structures were developed using structural analysis software.

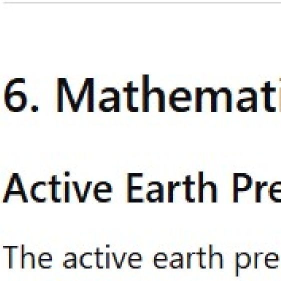
The analysis procedure involved:

1. Development of bridge geometry.
2. Assignment of material properties.
3. Application of support conditions.
4. Application of dead load, live load, earth pressure, and seismic loads.
5. Static and dynamic analysis.

The following parameters were evaluated:

- Maximum displacement
- Base shear
- Natural time period
- Frequency
- Acceleration response
- Maximum stress

VI. MATHEMATICAL FORMULATION



6. Mathemat

Active Earth Pre

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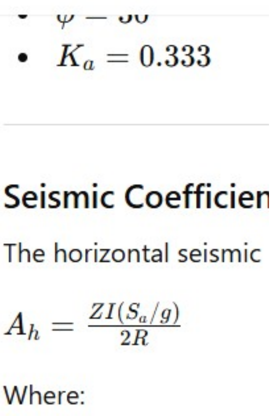

- $\varphi = 30$
- $K_a = 0.333$

Seismic Coefficien

The horizontal seismic

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

Where:

VII. RESULTS AND DISCUSSION

7.1 Comparative Seismic Performance

A comparative analysis between pier bridge and box bridge configurations was carried out.

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

The box bridge exhibited approximately 9.44% lower displacement, indicating superior rigidity and 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

Base shear increased with increasing span length due to greater seismic mass.

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

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

3) Time vs Acceleration

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

4) Maximum Absolute Stress

Span Length	Stress (N/mm²)
5 m	0.0328563
10 m	0.028527
15 m	0.0282977

VIII. CONCLUSION

The present study investigated the structural performance of RCC underpass bridge systems under vehicular and seismic loading conditions.

The following conclusions were drawn:

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

IX. FUTURE SCOPE

Future studies may include:

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

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