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A Review on Comparative Study on Structural Performance of Underpass Bridge with Vehicular and Earthquake Loads

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Abstract— **This study aims to evaluate and compare the structural performance of underpass bridges subjected to both vehicular and earthquake loading conditions. Underpass bridges are vital infrastructural components that must withstand diverse load combinations to ensure safety and serviceability. The research involves the calculation of base shear using the seismic coefficient method and the determination of the fundamental time period in accordance with IS 1893:2016. Vehicular loads are applied as per relevant design codes to simulate real traffic conditions, while seismic loads are incorporated using dynamic analysis methods to capture the bridge's response under earthquake excitations. The comparative analysis focuses on key structural parameters such as displacement, bending moment, shear force, axial force, and stress distribution. Through this approach, the study identifies the variations in performance under static and dynamic conditions, providing insights into the most critical load effects governing bridge design. The outcomes of this research are expected to assist in improving the seismic resilience and overall structural efficiency of underpass bridges.**

Index Terms— **Underpass bridge, Base shear, Dynamic analysis, Earthquake load, Vehicular load, IS 1893:2016, Structural performance.**

I. INTRODUCTION

Bridges have always figured prominently in human history. They enhance the vitality of the cities and the cultural, social and economic improvement of the areas around them. Great battles have been fought for cities and their bridges. The mobility of army at war is often affected by the availability or otherwise of bridges. Bridges are Nation's lifelines and backbones in the event of war. Bridges symbolize ideals and aspirations of humanity. [7] They span barriers that divide, bring people, communities and transportation and facilitate commerce. Bridge construction constitutes an important element in communication and is an important factor in progress of civilization. A bridge is a structure built to span physical obstacles such as body of water, valley or road for the purpose of providing passage over the obstacle. [9] Design of bridges varies depending on the function of the bridge, nature of the terrain where the bridge is constructed, the material used to make it and the funds available to build it. This study the performance of R.C.C Underpass Bridge by applying various analytical techniques. Two-dimensional finite element model of R.C.C Bridge is established and analysis is performed for static loading. The outcomes of static loads actually arriving on R.C.C Bridge are studied. Also, as the box structure directly rests on soil and also soil pressure acts at the sidewalls, it is essential to examine the Soil Structure Interaction of structure. [13].

A. History of Bridge Development

The history of development of bridge construction is closed linked with the history of human civilization. Nature fashioned the first bridge. The tree fallen accidentally across the stream was the earliest example of a beam type bridge. [18] Similarly the natural rock arch formed by erosion of the loose soil below was the earliest forever of the arch type bridge. Likewise, the creepers hanging from tree to tree gave birth to suspension bridges. The primitive man imitated nature and learned to build beam and suspension bridges. Since the primitive man was a wanderer in search of food and shelter, the first structure he built was bridges. [25]

Bridges have a different type of Structure. Underpass Structure is one type of Bridge Structure. In which the Traffic is Heavy on the crossing or at the junction, Underpass Structure is Provided. Underpass structure is a called one type of Grade Separator. [14] In Highway which is above 4 lane or 6 lane Highway underpass is frequently provided at the junction and crossing due to heavy traffic. Generally, Village or town Area is near to Highway then this village or town traffic is not disturbed to Main Highway traffic that provide underpass. In underpass Bridge Structure is many types Vehicular underpass, Pedestrian Underpass or Cattle Underpass and Flyover etc. [10] This all are the called Grade Separator required width of Span is necessary more than provide the flyover but span width is providing less so go through the Vehicular underpass and Pedestrian/cattle Underpass. In pedestrian Underpass is designed for normal vehicle like cycle or Cow car etc. and used for pedestrian. Here show some photos of VUP, PUP and Flyover. [11]

Fig 1.2 VUP & PUP type Underpass (Ref- Highway Correspondence)

II. STATE OF DEVELOPMENT

A. Literature Review

Piyush Tiwari et.al. [1] In the last few decades, there has been an enormous increase in traffic volume on highways due to population growth and rapid urbanization. To maintain traffic flow, numerous new highways and flyovers have been built. As part of the modern world, bridge construction has come to be considered of international importance. It provides passage over obstructions without closing off the path below. Recent technological advancements have made conventional bridges obsolete. Innovative and cost-effective structural systems have replaced conventional bridges. These days, box type bridges are becoming more popular in modern highway systems, including urban interchanges, because of their efficient dispersal of congested traffic, their economic considerations, and their aesthetic appeal. The structures have many advantages that are useful in freeway and bridge construction, including structural efficiency, serviceability.

Baishun Xu et.al. [2] For medium- and small-span bridges, the weight of the superstructure in steel–concrete composite girder bridges are lighter than that of a reinforced concrete girder bridge. However, it is still uncertain whether steel–concrete composite girder bridges exhibit superior seismic performance compared to reinforced concrete girder bridges. This study quantitatively compared the seismic performance of the two types of bridges. Using the theory of probabilistic seismic demand analysis, the seismic vulnerability curves of bridges were derived. To conduct seismic demand analysis for probabilistic analysis on the OpenSEES platform, bridge samples were generated using the Latin hypercube stratified sampling method, which considers the uncertainties associated with the two types of bridges. The vulnerability curves of the piers, bearings, abutments, and the system of the two bridges were established using probabilistic analysis of the time history analyses. The results showed that the seismic vulnerabilities of components and the overall system of the steel–concrete composite girder bridge were both lower than those of the reinforced concrete girder bridge. When the peak ground acceleration (PGA) of the ground motion was 0.3 g, the moderate and serious damage probabilities of the piers in the steel–concrete composite bridge were only 54.61% and 60.89%, respectively, of those of the reinforced concrete bridge. Consequently, replacing the upper reinforced concrete girders with steel–concrete composite girders can significantly improve the seismic performance of a large number of existing bridges.

Halil İbrahim Yumrutaş et.al. [3] concrete, stone, steel, and wooden materials are used in the construction of pedestrian over/underpasses. However, there has still been uncertainty when preferring the construction of over or underpass. In this study, an inventory of pedestrian overpasses and underpasses in Karabuk-Safranbolu region was presented in the light of various parameters. Two kinds of overpasses (constructed as steel and reinforced concrete) and an underpass were selected, and cost analyses were carried out comparatively. Additionally, face-to-face surveys were carried out with 300 people in 3 different over/underpass locations, and the results were evaluated by SPSS (statistical package for social sciences) ANOVA (analysis of variance). The advantages and disadvantages of over/underpasses in terms of cost, safety, ease of use/comfort, saving of time, user preference, aesthetic, construction period are revealed by means of the survey studies, data collected by General Directorate of Highways (KGM) and on-site observations, and then presented with tables and graphics. There has not been any standard, regulation, code, or design and safety criteria for the construction of underpasses/overpasses in our country and it is thought that this study will contribute to decision-making process of related authorities such as municipalities, general directorate of highways, etc.

Mr. Vishwasu Gopalraje et.al. [4] The intersection of railway track and the road at the same level is referred to a level crossing. In the urban areas the level crossing is generally monitored by qualified railway personnel who monitor the train movement and close the level crossing gate to stop the interfering road traffic but such closing of gates leads to congestion in road traffic and also causes loss of time to road users. Road under bridge and road over bridge are considered as solutions for avoiding level crossings of roads and railway track. There are 3 main methods in construction of road under bridge. Box pushing method, Cut and cover method, rolling technique using RH girder. In this we discuss about the implements, soil friction, effects required, capacity of jacks and there uses, skew angles and at square angles.

Ye Dan et.al. [5] Taking the new underground box culvert under passing the special bridge of Guangzhou-Qingdao Intercity Trans-Guangdong-Qingdao Expressway in the flooding remediation project around Guangzhou Vehicle Factory as an example, the impact of the underground box culvert proximity and under passing construction process on the proximity pier of the special bridge at Huaian Station was studied. Firstly, the settlement values and lateral and longitudinal horizontal displacement values of the underpass pier at different construction stages were obtained by on-site monitoring. Subsequently, a numerical simulation model was established by PLAXIS 3D to further analyze the dynamic response law of the pier. Finally, the construction control standards and control measures for underground box culvert under passing high speed railway bridges are proposed through parametric analysis of the excavation proximity and excavation depth of the underground box culvert. The research results show that during the construction of new underground box culvert underpass, the settlement and displacement conditions of the pier of Guangqing Intercity Bridge across Guangqing Expressway are within the specification limits, and in order to ensure the absolute safety and smoothness of train operation, it is suggested that the excavation depth of new underground box culvert underpass should be kept within 6 m, and the excavation proximity should be kept above 5 m when it exceeds 6 m.

Hamayoon Kheradi et.al. [6] an underground structure buried in a soft ground located in a seismic-active region may experience intolerable deformation due to earthquake loading. The collapse of Daikai Station of the Kobe subway line during the 1995 Hyogoken-Nambu Earthquake demonstrated that underground structures may also sometimes be at high risk for failure in a huge earthquake. In particular, box culverts constructed in a soft ground with a thin overburden are vulnerable to earthquakes. Some previously constructed box culverts do not meet the present requirements of seismic design standards. In this paper, numerical analyses and 1-g shaking table tests are conducted to evaluate the effect of partial ground improvement (PGI) as a seismic countermeasure for the above-mentioned existing box culverts. Particular attention is paid to the optimum pattern of PGI that can most efficiently reduce the impact of an earthquake on a box culvert. The underground structure of Daikai Station is taken as an example and its physical and geometric conditions are used to model the box culvert in the analyses and the tests. In order to accurately consider the influence of the soil-structure interaction (SSI) on the underground structures, both the soil and the box culvert are considered in the analyses and the shaking table tests. Four different patterns of PGI are considered. Based on the analyses and the tests, an optimum pattern for the PGI of existing box culverts is proposed.

Paulo Rui Anciaes et.al. [7] this paper reports the results of a study to understand the preferences of pedestrians towards using different types of road crossing facilities. A preliminary qualitative study found that people's perceptions about crossing facilities are shaped by aspects such as safety, convenience, crossing time, accessibility, and personal security. The main quantitative study consisted of a stated preference survey implemented in three neighbourhoods in English cities near busy roads. Participants were first asked to indicate how comfortable they felt using different types of crossing facilities. Footbridges and underpasses were systematically rated below signalized crossings. Participants were then asked to choose between walking different additional times to use certain types of crossing facility or avoid crossing the road altogether. The analysis of the choices using a mixed log it model found that on average participants are willing to walk an additional 2.4 and 5.3 min to use a straight signalized crossing and avoid using footbridges and underpasses, respectively. Women and older participants were willing to walk longer additional times to avoid those facilities. Participants only avoid crossing the road if the additional time to use straight signalized crossings is at least 20.9 min. The estimated values for the willingness to walk were slightly smaller when using a conditional log it model. The study provides information that is useful for policy decisions about the frequency and the type of pedestrian facilities provided to cross busy roads.

M. Bhardwaja et.al. [8] Roads can form barriers to movement for many species, and may reduce the ability of individuals to access foraging and breeding habitat. The impacts of roads on terrestrial fauna have been well studied; however, little is known of the impact of roads on insectivorous bats. Wildlife crossing structures (e.g. fauna underpasses) may reduce the barrier impacts of roads and improve connectivity across roads. Use of underpasses by wildlife likely varies among species depending on their movement behavior. In this study, we investigated whether the flight patterns of insectivorous bats influenced their use of underpasses. We monitored bat activity under and above 6 open-span bridges, 6 box culverts and 6 unmitigated sites along a major highway in Australia. We used Poisson regression models within a Bayesian framework of inference to compare the activity of 12 bat species (grouped into three guilds based on their flight patterns: clutter-adapted, edge-adapted, and open-adapted species) under the structures, over the road above the structures, above unmitigated segments of the highway, and in the vegetation adjacent to the roads. Bats were less active above the road than they were in the surrounding vegetation or under bridges. Two of the three guilds (i.e. seven species) crossed the highway more under bridges than they did under culverts or by going over the road, which suggests that bridges may reduce barrier effects of the road better than culverts. Installing bridges instead of culverts may better reduce the impacts of roads on multiple insectivorous bats species with a single structure type.

Yasuo Sawamura et.al. [9] The three-hinge precast arch culvert consists of two segmental precast units and three hinge points. It harnesses the passive resistance of an embankment by permitting deflection, resulting in a mechanically stable structure. However, the design of the three-hinge precast arch culvert differs from that of a conventional culvert, prompting the mechanical behavior of the culvert to become an important issue. In this study, therefore, 1/5 scale model tests were conducted on a three-hinge precast arch culvert to measure the changes in the inside width and earth pressure acting on the culvert at each step in order to investigate the culvert's mechanical behavior at each construction stage. Moreover, the deflection measurement of the culvert was obtained at the in-situ construction site. The results indicate that the arch members were displaced according to the embankment depth in a similar manner to the design load. Therefore, the horizontal earth pressure, which was larger than the earth pressure at rest, acted on the culvert at the end of its construction.

Manuel F. Báez H et.al. [10] although underpasses are low-cost solutions widely used in high-speed railway lines, their dynamic analysis is complex given the large number of variables involved in the problem and the high computational cost of detailed 3D models. The objective of this study is therefore to present a simple and fast 3D method for estimating the dynamic behavior of culvert-type underpasses subjected to dynamic loads induced by high-speed trains under normal operating conditions. This model was adjusted to data gathered in situ during a measurement campaign on the high-speed line between Segovia and Valladolid in Spain. The prediction method is based on a sub-structuring approach with three key ingredients: an emission 2D finite element model that simulates the track; a slab model based on Kirchhoff theory and the Rayleigh-Ritz method using trigonometric shape functions; and sidewall-models using a formulation of a finite-length beam on a viscoelastic foundation. The emission model estimates the contact forces for the slab using the vertical dynamic behavior of the railway track, and the slab model accounts for the contribution of the soil-structure interaction that takes place at the sidewalls by means of the frequency-dependent stiffness at the corresponding joints.

B. Gap Identification

Existing literature has predominantly focused on static load assessments, giving insufficient attention to the combined and interactive effects of vehicular loads and earthquake-induced dynamic forces. This gap is significant because underpass bridges often experience simultaneous or sequential loading from traffic and seismic events. Additionally, the soil–structure interaction (SSI), especially the lateral earth pressure acting on the walls of box-type underpasses, has been inadequately studied, despite its crucial influence on the global stability, deformation pattern, and overall seismic response of the structure.

III. FINDING

Given these limitations, there remains a clear need for comprehensive studies addressing these overlooked aspects. Therefore, the present research aims to fill these gaps by conducting a comparative structural performance evaluation of box-type underpass bridges without piers, subjected to both vehicular and seismic loading conditions. The study examines key response parameters including base shear, natural time period, displacement, bending moments, shear forces, axial forces, and stress distribution following the guidelines of IS 1893:2016 and other relevant design standards.

IV. PROBLEM STATEMENT

Underpass bridges are vital urban structures subjected to continuous vehicular loads and potential seismic forces. Conventional design practices often evaluate these loads separately, which may not accurately represent the actual structural behavior under realistic conditions. Moreover, the effect of span length variation on the performance of underpass bridges under vehicular, earthquake, and combined loading has not been adequately studied. Hence, this study aims to model and analyse underpass bridges with varying lengths of 5 m, 10 m, and 15 m to compare their structural responses under vehicular loads, earthquake loads, and combined load conditions in accordance with relevant codal provision.

[1] Type of Structure: Reinforced Concrete Underpass Bridge

[2] Structural System: RCC box-type underpass structure

[3] Geometric Configuration:

- Overall width of underpass: approximately 8.74 m
- Clear vertical clearance: 3.84 m
- Internal width between side walls: varying from 3.06 m to 4.74 m
- Initial span length: 5.0 m,

[4] Span Length Variation:

- Three models are developed with span lengths of 5 m, 10 m, and 15 m to study the influence of length on structural performance.

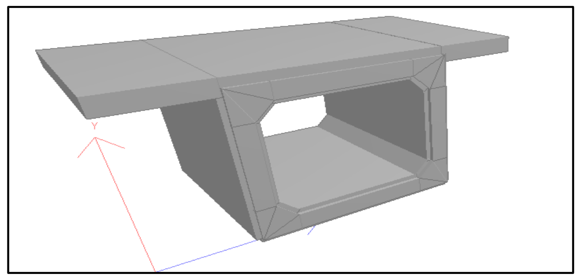


Fig 2 3D View of model

V. COMPARATIVE ANALYSIS

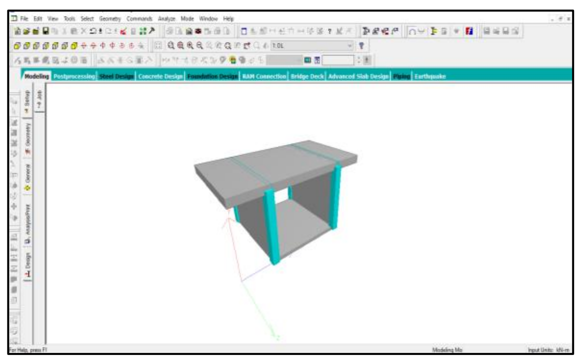


Fig 3 Bridge with Pier

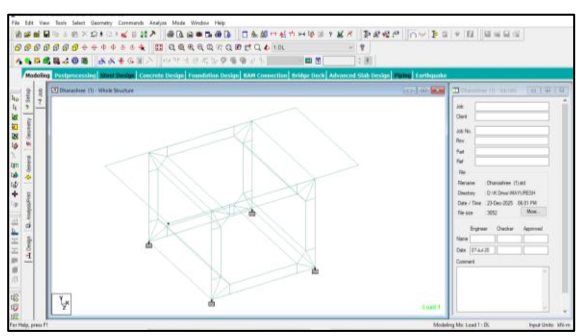
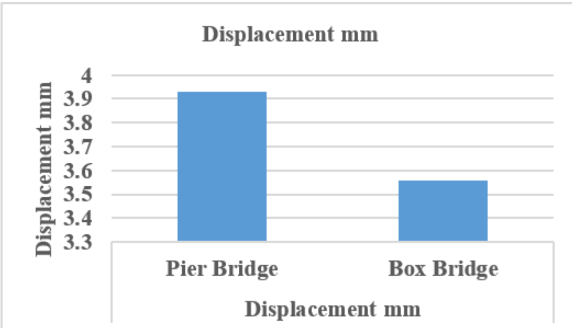


Fig 4 Bridge with Box

Table 1 Result for Displacement mm

Displacement mm	
Pier Bridge	Box Bridge
3.93	3.559



Graph 1 Result for Displacement mm

VI. CONCLUSION

Underpass bridges are important components of urban transportation infrastructure and must be designed to safely withstand both vehicular and seismic forces. In this study, reinforced concrete underpass bridges with span lengths of 5 m, 10 m, and 15 m were modeled and analyzed to evaluate their structural behavior under different loading conditions. A comparative analysis was also carried out between pier bridge and box bridge configurations to determine their relative performance.

From the analysis results, it was observed that the structural response of the underpass bridge varies significantly with the change in span length and structural configuration. As the span length increases, the displacement and overall structural demand on the bridge also tend to increase, indicating the importance of careful design considerations for longer spans. The comparison between the two bridge types showed that the RCC box bridge exhibited lower displacement (3.559 mm) compared to the pier bridge (3.93 mm), demonstrating better stiffness and structural stability under the applied loading conditions.

The study highlights that considering combined effects of vehicular and seismic loads provides a more realistic understanding of bridge behavior than evaluating these loads independently. The results indicate that the box-type underpass structure performs more efficiently in terms of displacement control, making it a preferable option for underpass bridge design in urban areas.

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