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A Critical Analysis of Seismic Performance of RCC Skewed Bridges

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Abstract—*Earthquakes are a great threat to bridges because of their unpredictable nature. Bridges should be capable to withstand static as well as dynamic loads, especially the earthquake load. Newly constructed bridges are frequently skewered because to space restrictions in crowded metropolitan settings. Skew bridges may suffer serious damages when struck by a strong earthquake, Severe earthquakes have been associated with a number of seismic problems, including pier collapse, deck unseating failure, expansion joint failure, etc.. This review paper presents an overview of the state-of-the-art techniques for seismic analysis of reinforced concrete (RCC) skewed bridges. The paper starts with a brief introduction to the characteristics of RCC skewed bridges and their response to seismic loads. The paper also discusses the different seismic analysis approaches for RCC skewed bridges, such as linear and nonlinear static analysis, linear and nonlinear dynamic analysis. Finally, the paper concludes with a discussion on the current research trends and future directions for seismic analysis of RCC skewed bridges. Overall, this review paper provides a comprehensive understanding of the state-of-the-art techniques for seismic analysis of RCC skewed bridges, which can be beneficial for academics and professionals involved in bridge design and earthquake engineering*

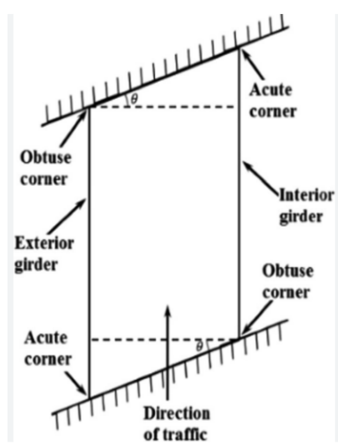
INTRODUCTION

For engineers creating static and dynamic analyses for straight normal bridges, several design regulations and recommendations have been created. When it comes to the structural reactions of skewed highway bridges, there is still a substantial area of uncertainty. Current rules don't contain many specific instructions, which is primarily to blame. Skewed bridges are ones with a longitudinal axis that is not perpendicular to the abutment. They can be the result of a number of things, including natural or man-made barriers, hilly terrain, complicated junctions, or a lack of available space. Skewed designs are frequently utilised in newly built bridges because they allow for a wider selection of road building project options, need less area, and enable construction in even the most crowded regions. Unfortunately, skewed highway bridges are especially susceptible to serious damage from seismic loads, as previous seismic events have shown.

Skew bridges' force flow is substantially more complicated than that of right-angle bridges. When an object strikes at an angle, this intricacy shows itself as a distinctive seismic reaction. Because of their skewed orientation, these bridges have a propensity to spin in the horizontal plane and run the risk of falling off the supports at the sharp corners. Skewed bridges have a tendency to take a diversion towards the obtuse corners of the bridge rather to the support, as is the case with right angle bridges where the load path proceeds directly in the direction of the span. One of the obtuse corners is consequently the site of a coupling of transverse and longitudnal reactions, which causes rotation in the direction of increasing skew angle.

The seismic performance of bridges is a key factor in determining their resilience to natural catastrophes like earthquakes. Due to their complicated shape and unequal load distribution, Skewed bridges are more vulnerable to seismic action.. To assure their safety and dependability during earthquakes, it is crucial to assess the performance of skewed RCC bridges in seismic events.

The goal of the study is to analyse how skewed bridges respond to seismic stress and to pinpoint the variables that have an impact on how well they operate. The study makes acceptable recommendations for improving the seismic resilience of skewed RCC bridges. The results of this study will help create standards for design and best practises for building skewed RCC bridges that can survive powerful earthquakes.



The forms of seismic analysis frequently applied in engineering practise are as follows:

1. Linear static analysis, often known as static equivalent analysis. The structure's response to seismic forces is assumed to be linear and elastic in this, the most basic kind of seismic analysis. It is employed to assess the forces and moments produced by static loads acting on the structure.
2. Linear Dynamic Analysis, commonly known as time history analysis or response spectrum analysis. Using linear equations of motion, this approach takes the structural reaction to earthquake ground motion into account. Although it can take into account the ground motion's time-varying characteristics, it makes the assumption that the structure will behave linearly.
3. Pushover analysis, also referred to as nonlinear static analysis. The pushover analysis technique is used to assess a structure's reaction outside of its linear range of activity. It models the distribution of plastic deformations and the building's ability to withstand seismic stresses.
4. Nonlinear dynamic analysis (time history analysis with nonlinear behaviour). This approach takes into account the ground motion's time-varying characteristics as well as the structure's nonlinear behaviour. It can model the emergence of plastic hinges in a structure as well as the structural reaction to significant seismic occurrences.

LITERATURE REVIEW

Deepak and Sabeena(2015) uses ANSYS software to simulate a simply supported skew slab with varying skew angles using finite elements. In this investigation, skew angles ranging from 0° to 30° were used. After doing a nonlinear finite element analysis on each skew slab, it was discovered that as the skew angle grows, so does the uplift at both acute corners. According to the findings, the maximum deflection for skew slabs lowers as the skew angle grows, and the load bearing capacity rises as the skew angle increases[1].

Haque and Bhuiyan(2015) investigated the response of a simple span RC deck girder bridge under seismic excitation for variety of skew angles. In this regard, linear time history analysis was used to take into account a 3-D model bridge that used the finite element approach. The time history analysis makes use of a conventional direct time integration methodology. In accordance with the design acceleration response spectrum obtained from earthquakes of low to moderate magnitude, the longitudinal direction of the bridge was exposed to an earthquake ground motion record.. The bearings of external girders were found to be seismically more sensitive than interior girders. Study was done on the mode forms for skewed and non-skewed decks. The analytical results showed that the reactions of the skewed bridges are considerably different from those of the nonskewed bridges, and that they depend both on the features of ground motion and the skew angles[2].

Maleki(2002), By reducing the degrees of freedom associated with the superstructure and assuming that the concrete deck is stiff in its own plane, the seismic analysis of slab-girder single-span skewed bridges may be made simpler. In a parametric study of bridges with spans up to 30 m and skews ranging from 0 to 60 degrees, linear finite element response spectrum dynamic analysis was carried out on bridges with decks modelled as rigid and flexible shell elements. The analysis of skewed slab-girder bridges with spans up to 20 m and skews up to 30 degrees was shown to be simplified by the assumption of a stiff diaphragm action for the deck, as long as the typical spacing between the girders is retained. This judgement is based on a comparison of the seismic demand on supporting elements for rigid and non-rigid decks and an examination of the stresses for flexible decks, which revealed that they were insignificant. All slab-girder bridge widths can use these conclusions[3].

Heidari and Gerami(2019) In order to better understand how the skew angle impacts the seismic response of curved and skewed bridges, research has been conducted. The finite element programme has been used for modelling and analysis. Field testing was done to verify two curved bridges and 31 skewed bridges. The findings demonstrated that deck rotation increases with increasing skew angle and occurs near the location where ramp bridges link to abutments. The reaction intensity rises as the angle between the global longitudinal direction and the skew direction increases, and vice versa. The seismic reactions of these bridges are not significantly impacted by the skew angle shift in far-fault zones, but it has a notable impact in near-fault zones[4].

Kothari and Murnal(2015) conducted research to ascertain how skewed highway bridges respond to seismic and service loads. With the aid of the FEM programme SAP2000 and various skew angles (ranging from 0º to 50º), a linear time history analysis of a 3D-model bridge was conducted as part of the study. Both a longitudinal and a transverse earthquake ground motion record are applied for the Imperial Valley and Northridge quakes. The study demonstrated that when skewness increased, deck acceleration and bridge bearing responses also increased. Additionally, as skew angles increased, external girder force increased more than internal girder force, and torsional moments also increased as skewness increased[5].

Meng Lui and Liu(2000) in The study presents a basic mode for the analysis of skew highway bridges and stiffness eccentricity bridges. The model is capable of capturing all the crucial elements that have an impact on various bridge types' dynamic reaction. Using the model, formulas are created for calculating earthquake reaction, and factors that have a major impact on the dynamic response of the bridges are found. The study shows that a skew bridge's response is dependent on a variety of variables, including the skew angles, the natural frequencies, and the ratio of rotational to translational frequencies, as well as the aspect and stiffness eccentricity ratios of the deck and the skew angles. Bridges with higher stiffness eccentricity ratios, deck aspect ratios, and skew angles exhibit less dependence on these variables. The results of the study demonstrate that a number of variables influence the dynamic behaviour of skew bridges. Additionally, they demonstrate that once the rotational to translational frequency ratio surpasses 1.6, neither the stiffness eccentricity nor the skew angle have a substantial impact on the maximum normalised displacement of the bridge[6].

Ghobarah and Tso(1973), Following the San Fernando earthquake in 1971, which damaged a number of skewed highway bridges, a study on these bridges' dynamic response was conducted. The outcomes of that study are discussed in this essay. The authors looked at the Foothill Boulevard Undercrossing, SE Bridge in the San Fernando Valley, which had intermediate supports broken, using a beam model that could bend and twist. According to the analysis's findings, coupled flexural and torsion vibrations of the bridge can be exacerbated by the vertical ground motions that occur during an earthquake, and this may be the primary reason for damage for many skewed highway bridges. The study comes to the conclusion that there is a significant high frequency component in the vertical ground motion, which makes highway bridges near faults more vulnerable to earthquake damage[7].

Mohti and Pekcan(2013) evaluated the earthquake resistance of skew reinforced concrete box girder bridges. To learn more about the seismic response characteristics of skew box girder bridges, the study developed two-span, three-dimensional beamstick models of highway bridges with skew angles ranging from 0° to 60°. A number of parameters and circumstances, including skew angle, ground motion intensity, soil condition, abutment support conditions, bridge aspect ratio, and foundation-base conditions, were investigated for their effects on the overall seismic reaction`. The findings indicated that the deformations brought on by pinned foundations are significantly higher, yet the scenario with a permanent foundation required more force to bend the component. It was also discovered that the bridge's longitudinal rigidity diminishes as the skew angle rises, which results in an increase in displacement as the skew angle rises[8].

Deshpandey et al.(2018), used SAP2000 to perform seismic analysis of box and T girder bridges for a certain span utilising the response spectrum approach. . The foundation, girders, and deck responses are investigated. The optimal option between the two girder types in terms of earthquake reaction was also attempted to be established, along with the skew angle at which skew bridges are equivalent to straight bridges. Conclusion: Skewed box girder bridges perform better seismically than T girder bridges for the investigated span up to skew angles of 15 degrees. Skewed bridges show comparable responses to straight bridges. Using the data from this investigation, the following findings are made. The reactions of skew bridges are similar to straight bridges up to a skew angle of 15 degrees. For a given span, skewed box girder bridges perform more seismically as a whole than skewed T girders[9].

Kwon and Jeong(2013), The unseating of decks, which was common in the 2010 Chile earthquake, is one of the failure types of bridges following earthquakes that are included in the article. In Chile, skew-angled bridges supported by elastomeric bearings were more vulnerable to deterioration. In the eastern and central United States, similar bridge construction methods are frequently used. The project is only focused on one- and two-span bridges in the CEUS and seeks to understand how skewed bridge decks supported by elastomeric bearings respond seismically. To ascertain how different factors impact the seismic displacement requirement, the study employs closed-form vibration modes and nonlinear response history analysis. This article's study reveals how many factors, such as skew angles, aspect ratios, the number of spans, and ground motion types, may affect the maximum displacement demands superstructure of bridge. Since the skew angle has a more obvious impact on reactions in the abutment-normal direction, amplification factors are recommended for a cautious estimation of the maximum displacement demand. The findings may be utilised to create shear keys or additional energy dissipation devices to manage bridge deck reaction, as well as bearing seat width. To verify the results, experimental research are advised[10].

Bjorsson et al (1997) done a detailed parametric analysis of two span skew bridges with stiff decks. Maximum relative abutment displacement (MRAD) was thought to be a crucial factor in this study's analysis of failure brought on by unseating. The interaction between the deck and the abutments was shown to have a significant impact on MRAD. Between 45 and 60 degrees was shown to be the key range for the skew angle at which the rotational impulse caused by impact is maximised. It has been demonstrated that MRAD (span to width ratios) for all bridge configurations tends to rise linearly for skew angles under 30 degrees[11].

CONCLUSION

The reviewed literature provides insights into the skew angle's effect on the behaviour of different types of bridges under various loading conditions. The studies demonstrate that skew angle has a significant impact on the uplift, deflection, seismic response, and dynamic behaviour of bridges. The use of finite element analysis has been instrumental in simulating and predicting the behaviour of skewed bridges. The findings suggest that the uplift at acute corners increases with increase in skew angle while the maximum deflection decreases, and the load-bearing capacity increases. Moreover, the seismic reactions of skewed bridges are significantly different from those of non-skewed bridges and depend on both the features of ground motion and the skew angles. The reviewed literature offers valuable insights for designing and analysing skewed bridges, and highlights the importance of considering skew angle in bridge design and assessment. Further research in this area is required to explore the effects of other factors, such as material properties, support conditions, and traffic loads, on the behaviour of skewed bridges.

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