A Structural Parametric Study of Skew Bridge with Analytical and Experimental Methods: A Review

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Abstract
A bridge is a crucial building element needed for the transportation system however, due to the site characteristics, it is never feasible to build a standard bridge. A skew construction is required if the alignment of the road is not perpendicular or crosses the river at an angle different than 90 degrees. A skew bridge is a bridge that is built obliquely between abutments. The behavior of skew bridges under various loading circumstances is investigated using a variety of analytical techniques and software. The study examines the effects of skew angles on internal forces, displacement, bending moment, shear force, and natural frequency in bridge components. In this paper, an attempt has been done to rigorously carry out the literature review to understand the behavior of the intricacy of force flow in skewed bridges compared to straight bridges and how the behavior of the bridge is greatly influenced by the skew angles. The investigation reveals that skew angle has a significant impact on the shear force, bending moments, and torsional moments in skew bridges. Further, there is a good scope for studying the behavior of skew bridges with a different skew angles in the seismic design and evaluation of highway bridges.

Keywords: *Skew bridge, FEM, Torsion reinforcement*

1. Introduction
A bridge is a crucial building element needed for the transportation system however, due to the site characteristics, it is never feasible to build a standard bridge. A skew construction is required if the alignment of the road is not perpendicular or crosses the river at an angle different than 90 degrees. In other words, a Skew Bridge is a bridge that is built obliquely between abutments. Skew Angle is the angle formed by the center line of the abutment and the normal to the center line of the bridge. The bridge plan may appear in parallelogram form in the plan view for simplicity [1]. Skewed bridges are the greatest choice for cost-effective and

sustainable construction because it is very difficult to align straight bridges in various terrain circumstances, such as mountainous regions, rivers, etc. Typically, a bridge is designed as a normal bridge if its skew angle is less than 20°. Thus, the presence of a skew angle affects the geometry and behavior of a skew bridge. The skew angle of the substructure can dramatically change how a skewed bridge responds structurally to loads in the slab and responses on the abutments [2]. Due to the worsening traffic circumstances in India today, skew bridges are the greatest alternative for facilitating quick and effective traffic flow. In a non-skewed bridge, the deck acts orthogonally in flexure, that is, both in longitudinal and transverse directions, with the major moments being in both of these directions.

It is clear that flexure directly transmits the load from the slab to the supports. Due to the bi-directional curvature's modest twisting moments at the supports, they can be ignored. On the other hand, in skew slabs, the slab generally curves along the line connecting the obtuse-angled corners, and the load path tends to take a shortcut across the strip of the area between the obtuse-angled corners. The aspect ratio (skew span to deck width) and skew angle affect this principal bending strip's breadth. Only the cantilevered strip itself receives the load from the sections on either side of the strip, not the supports. The weight is redistributed across the entire length after being transmitted from the strip to the support over a predetermined length of the support line [3].

1.1. Components of Bridge

The main components of the bridge are as follows

- Girder
- Bearings
- Deck
- Piers
- Abutment

1.1.1. Girder

Large horizontal beams called girders serve as a building's main structural support and are joined to all other smaller beams to form the "skeleton" of the building. It is frequently employed as the primary horizontal structural support for smaller beams since it can typically handle longer spans and heavier loads than a standard beam.In single-span bridges, the main girders are typically parallel to the bridge axis, but they could be square to the abutments if the skew is very great (more than 45°) or the bridge is very wide (far wider than its span).Although the bridge may be skew to the object it crosses in some circumstances, supports might instead be placed square to the axis of the bridge. Further increasing the spans may necessitate more area for the support foundations.

1.1.2. Bearings

A bridge bearing is part of a bridge that normally offers a platform for resting between the bridge piers and the deck.

1.1.2.1. The function of bearing:

- They move forces from the superstructure of the bridge to the substructure. There are mainly two sorts of loads: lateral loads like earthquakes and wind forces, and vertical loads like the weight of the structure and vehicle loads.
- To accommodate motions like thermal expansion, they allow movements like translation and rotation between bridge girders and pier caps.
- A unique kind of bridge bearing, neoprene bearing pads (rubber-like structure), loses energy through deformation and simplifies the load transfer mechanism, making analysis easier.

1.1.2.2. Types of bearings

- Rocker Bearings
  Rocker bearings enable swaying because of their curved surfaces. The bearing shifts as the bridge enlarges to facilitate movement in a horizontal plane. Steel is the main material used to make rocker bearings. Highway bridges frequently employ rocker bearings.
- Elastomeric Bearings
  The most common kind of bridge bearing in use today is elastomeric. Since the rubber itself allows for movement in the bridge, they are composed of rubber and without any moving parts. In contrast to other types of bearings that have moving components and are constructed of metal, elastomeric bearings are inexpensive to produce and do not require maintenance. If necessary, steel can be used to strengthen elastomeric bearings.
- Sliding Bearings
  Sliding bearings have a spherical surface for rotation and a flat sliding surface for horizontal movement.
- Spherical Bearings
  As their name implies, spherical bearings have a sphere-like form. These bearings don't permit movement in horizontal or vertical directions; they only permit rotation.
- Laminated Rubber Bearings
  Due to their low cost and straightforward designs, laminated-rubber bearings with alternate layers of rubber and steel sheets have been widely employed in small- to medium-span highway bridges in China in recent years. Large vertical loads can be supported by bearings, and they can also handle the thermal movements of the superstructure with little to no maintenance needed. The superstructures are supported by laminated-rubber bearings, and the only horizontal resisting force applied at the supports is friction.

1.1.3. Decks

The surface of a bridge's roadway or pedestrian walkway is known as the bridge deck.

1.1.4. Piers

The pier, which is a component of the substructure, transfers loads from the superstructure to the foundations while supporting the superstructure.

1.1.5. Abutment

The supporting substructure at the edges of a bridge span or dam is known as an abutment.

2. Literature review

Waghe and Deshmukh [1] studied CSIBRIDGE software to model and analyze skew bridges with various spans and skew angles for Class A Loading, which results in an increase in shear force for low skew angles. The nature of the bending moment changes by around 20% for each span and skew angle. As strong torsional moments are seen at skew angles of more than 30 degrees, it comes to an end. To offset these torsional moments in bridges, torsional reinforcing may be necessary. As the skew angle and span length rise, so does the bending moment.

Karuna and Reddy [2] designed and analyzed of box girder bridges, notably skew bridges, are the main topics of this research article. The configurations of the bridge deck, including various spans and skew angles, are described in the modeling and analysis section. For creating and analyzing the models, software (SAP2000) and material properties are specified. The study finds that for two and three-span decks, deflection decreases with increasing skew angle, whereas it increases for single-span decks. Under a dead load, bending moments typically decrease as the skew angle increases, with variances under a moving load. The study's findings suggest that the skew angle affects deflection and bending moments, especially for single-span decks. Higher skew angles may result in constant shear forces or an increase in shear forces, depending on the load type and deck configuration.

Meng and Ghasemi [3] outlines a skew bridge model experimental investigation. Tests in the experimental investigation were both static and dynamic. The static test was carried out to validate the bridge model's static behavior and to examine the stiffness characteristics and boundary conditions. whereas a dynamic analysis needed dynamic features like natural frequencies, mode shapes, and damping. With the main goal of proving the numerical results obtained using the bridge's finite element modelling, the design, construction, instrumentation, testing, and data processing of the skew bridge model were detailed. To confirm the accuracy of the finite element model, the experimentally obtained data were compared with those generated using finite element analysis for both the static and dynamic testing. The dual-beam stick model created for the streamlined analysis of skew bridges was also validated using the test data. The findings showed that the suggested structural models could reproduce the behavior of the test bridge.

Dhar and Mazumder [4] Use a 3D bridge model in the Finite Element Analysis program ABAQUS to analyze the behavioral characteristics of skew bridges in comparison to straight bridges. The study focuses on a reinforced concrete (RC) bridge with simple support and rising skew angles. According to the study, the support shear and mid-span moments of the obtuse longitudinal girders rise as the skew angle rises, while they fall for the acute longitudinal girders. The torsional moment in the obtuse-angled girder increases quickly as the skew angle increases. The results of this study emphasize the necessity of appropriate standards and guidelines for skew bridge design. In skew bridges, torsional moments are substantial.

Joseph and Manoharan [5]The impact of skew angles on the behavior and effectiveness of skewed bridges are discussed in the paper. The studies discussed in the book look into how different carriageway widths and span lengths affect highway bridges. It has been found that the bending moments decrease with increasing skew angle, whether the load is concentrated or applied at a knife edge. According to the research, a skew angle of 20° has the greatest impact on torsional moments and the potential destruction of the bridge.

Harba and Co. [6] The study or research report on the behavior of skew-angle reinforced concrete T-beam bridge decks with simple support. By examining various span lengths and skew angles using finite element analysis, the study examines the impact of skew angles on the behavior of these bridge decks the most. Bridge decks get thinner for skewed bridges due to the live load bending moment in T-beams. For skewed T-beam bridge decks, it was suggested that engineers do three-dimensional finite element analysis.

Tommy and Demeke B. [7]The significance of comprehending the dynamic behavior of skew bridges are discussed in the research paper. Field experiments can offer insightful data about the dynamic behavior of skew bridges, according to the report. According to the calibration test results, calibration factors were established for each strain gauge point along various bridge lines. The natural frequencies, mode shapes, and damping ratios were revealed by the modal test. It concludes that for skew angles between 0 and 30, the influence of skew on the bridge's static and dynamic behavior is negligible.

Amjadian and Kalantari [8]The dynamics of skewed highway bridges, including their mode shapes and natural frequencies, play a significant role in how they behave during earthquakes. The article you cited suggests a straightforward approximation approach for figuring out the seismic pressures, natural frequencies, and displacements of skewed highway bridges with continuous stiff decks. In addition to deriving the equations of motion for the dynamic model, this article also provides a step-by-step computational process for figuring out natural frequencies and internal forces. The suggested technique seeks to offer a straightforward and precise method for early analysis and design of skewed highway bridges, particularly in the conceptual design stage.

B. Patra and V. Kumar, [9]The paper refers to a case study that examines how to skew slab culverts behave under typical IRC-70R wheeled loading. Analytical modeling utilizing FEM and the grillage analogy is included in the study. STAAD-V8i software, which aids in analysis and provides helpful information, is used to do the analysis. For skew angles up to 30°, the skew influence on support reactions and displacements is less noticeable. It is concluded that skew slab bridges can be efficiently analyzed using both grillage and finite element approaches. The aspect ratio also has an impact on how a skew slab behaves. In comparison to greater aspect ratios at higher skew angles, the skew effect is more noticeable at lower aspect ratios.

Kothari and P. Murnal [10] Skewed highway bridges present difficulties for structural response and design standards because of their special features and susceptibility to seismic loads. This study used the finite element method to model a basic span concrete deck girder skewed bridge. To assess the bridge's seismic responses at various skew angles, modal analysis, and linear time history analysis were applied. According to the findings, skew angles have a substantial impact on the displacement, acceleration, internal forces, and bearing reactions of the bridge. At larger skew angles, it was discovered that external girders were more vulnerable to earthquake stresses than inside girders. To comprehend and construct skewed highway bridges, it is important to take into account the special qualities and problems they provide. To guarantee the structural integrity and seismic resilience of these bridges, more investigation and better regulations are required.

P. Naik and K. Gourav [11] STAAD Pro V8i software was utilized by the researcher to evaluate 70 bridge models. The span lengths and skew angles of deck slabs were varied, and they were modeled as plate parts. According to IRC-6 2017 norms, vehicle loads, such as CLASS-A and CLASS-70R, were applied to the slabs. Examined was the behavior of the edge beams and slabs. Except for a few instances in two-lane slabs, the bending moment in the edge beams decreased as the skew angle grew. In general, the study offered an understanding of how reinforced concrete bridge components behaved under various loading and skew circumstances. There are no considerably large changes in the behavior of the slab with CLASS-70R vehicle loading compared to CLASS-A vehicle loading.

3. Conclusions

The conclusions of the research papers are as follows:

1. skew angle has a significant impact on the shear force, bending moments, and torsional moments in skew bridges. A skew angle of 20° leads to larger torsional moments and potentially higher risks of bridge failure compared to other skew angles.

2. In multi-span skew slabs, deflection decreases with increasing skew angle whereas, it increases in single-span decks. Generally, bending moment decreases with skew angle under dead load but varies under moving load.

3. In multi-span decks Shear force slightly decreases with skew angle under dead load but increases under moving load. In single-span decks, it remains the same under dead load but increases with skew angle under moving load.

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