REVIEW ON REINFORCED CONCRETE SKEW SLAB

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ABSTRACT: There is an enormous growth in number of skew bridges or flyovers; especially in urban and developing cities. Due to ease in construction and constraints of space availability in cities; highway interchanges or grade separators, the skewed slab bridges are adopted instead of conventional straight slab bridges. The analysis of skew slab is more complicated as compare to straight slab due to variation in skew angle. Significant literature is available emphasize on lateral live load distribution, skew angle influence and application of different methods to determine the stress and moment parameter. A brief review of the available literature is presented in this paper

KEYWORDS: Skew slab; Limit analysis; Finite element; Skew angle; failure

INTRODUCTION

As a structural designer, most familiar issue or complexity while designing a river crossing, highway interchange or grade separator occurs is the space limitation or the site alignment. The escalating land costs nearby to the bridge site or sometimes proximity of the site area with the religious places like mosque/temple and restrictions on their demolition; compels a designer to propose a skew slab bridge instead of straight slab bridge. Sometimes, it is also not feasible to cross all the river/drains at right angles.

In early days, there used to be two-lane with earthen shoulders type of arrangement, but now with the span of time and tremendous traffic growth since then, escalation in design highway speed was also observed. Therefore, traffic volume and speed of 21st century divided four-lane highways having paved shoulder or urban highways in the cities, can't be restricted. So, to cope up with the IRC prescribed safety standards or regulations a reasonable straight road is required to accommodate skew bridges. The inclination of the centre line of traffic to the normal to the centre line of the river in case of river bridge or other obstruction is defined as the skew angle. Now, with the increase in skew angle, the resulting stresses in the skew slab alter significantly in comparison with the straight slab.

SKEW SLAB BEHAVIOUR

Generally, the skewed slab bridges were constructed after adopting conventional straight slab bridges design factors or analysis. No specific design parameters were considered regardless of the skew angle magnitude during analysis or design phase of the skewed slab bridges.

It is also well acquainted with the fact that load path followed for both the types of bridge is different, and load for a solid slab skew bridge usually tends to orient as a shortcut to bridge's obtuse corners. Such amendments in the load characteristics of the solid slab bridges and to some extent longitudinal girder bridges' bring the modification in the load path direction. And with this modification, some special characteristics as mentioned are also followed. First, significant torsional moments in the deck slab, secondly, decrease in the longitudinal moment. Then, increase in the transverse moment, after that concentration of reaction forces and negative moments at the obtuse corners and lastly small reactions and a possibility of uplift reaction forces at the acute corners. Such characteristics mentioned above add more complexities while designing a skew bridge over a normal/right angled bridge. Also, there is a reduction in the longitudinal bending moment and increase in torsion moment at the obtuse corner of the bridge with transverse bending in the deck for a large skew angles bridge. Such observations might be possible because some wheels of the HMV on skew angles are closer to the supports as compared to the right/normal bridges. With this, the slab tends to bend along a direction perpendicular to the abutments. Such action can transfer part of the load from deck slabs directly to the supports, rather than through the girders as in right bridges.

METHODS OF ANALYSIS FOR SKEW SLAB

Following methods could be adopted for analysis of skew slab, as they are designed on same design principles or theories of shear and bending as that for a beam. (1) Limit Analysis (2) Method of Grillage analogy (3) Finite strip method (4) Finite element method (FEM). The sub-topic below discusses the analysis method mentioned above, beginning with.

Limit Analysis

Plastic analysis and the theorems of limit analysis are powerful tools for modelling a structure's behaviour at ultimate and gaining an understanding of its safety. In the limit analysis, materials with sufficient ductility are considered such that the stress redistributions required by plastic theory can occur. Although plain concrete is not a particularly ductile material, reinforced concrete can exhibit considerable ductility if failure is governed by yielding of the reinforcement. This can be achieved if concrete's material properties are conservatively defined, and careful attention is paid to the detailing of the reinforcing steel. The ductile response of reinforced concrete has been demonstrated by decades of testing of large-scale concrete specimens. Limit analysis has traditionally been applied to slabs in the form of the yield-line and strip methods.

Method of Grillage Analogy

Grillage analogy method is consisting of a network of rigidly connected beams at discrete nodes for converting the bridge deck structure i.e. idealising the bridge by an equivalent grillage. Therefore, following four steps to be followed for obtaining design responses. (1) Idealisation of physical deck into equivalent grillage. (2) Evaluation of equivalent elastic inertias of members of grillage (3) Analyse the structure and (4) Interpretation of results. Here, the design judgments and experience of the designer will play a pivotal role as it involves the idealisation of the bridge deck as a plane grillage of discrete inter-connected beams.

Finite Element Method

This technique has been encouraged as an ideal method for analysing flat plates with highly irregular or unusual geometrics where direct design and equivalent frame techniques are invalid. By integrating the slab model with the three-dimensional plate, the combined effects of gravity and lateral loading conditions could be together assessed and then since core purpose of developing model is to determine design forces and moments are met, the remaining desirable designing is done using active design code.

LITERATURE REVIEW

Aspects like skew angle effect, lateral live load distribution, shear and reaction distribution, are being analysed and researched by various researchers and authors. Their reviews on the aspects mentioned above are presented under: -

Lateral Live Load Distribution on Skew Slab using FEM

(Khaleel and Itani1990), in order to determine moments in continuous right and skew slab-and-girder bridges due to live loads.. After undergoing their research, they concluded that larger skew angle significantly reduces the design longitudinal moment.(Khaloo and Mirzabozorg 2003), have also conducted 3D analysis for skew simply supported bridges of concrete decks with five concrete I-section precast prestressed girders using ANSYS. In their study, it has been concluded that arrangement of internal transverse diaphragms rather than other variables has a great effect on the load distribution pattern. Huang et al. (2004), also adopted finite element method to analyse two span continuos slab-on-steel girder composite structure. It has been concluded that the AASHTO LRFD formulas for transverse load distribution appear to be conservative for positive bending whereas these formulas appear to be accurate but not conservative for negative bending with the suggestion of usefulness of FEM for predict the acurate beahviour.

Effect of Skew Angle RCC Skew Slab

(Maher Shaker Qaqish 2006), compared AASHTO specifications prescribed for prestressed precast beams and cast in-situ slab bridge with the structural model developed using the finite element method. Hence, a research study carried out was basically observing the bending moment variation experienced in both longitudinal and transverse directions in the concrete slab of skew bridges (35^0 skew angle). As a conclusion to study carried out, the comparison showed that after applying AASHTO specification for slab bridge, the deck is safe and economical. (Menassa et al. 2007), for their study used general FEA program, SAP 2000 (1998) for generating the 3D finite element models. above research strongly recommended AASHTO Standard Specifications as well as the LRFD procedure gives better results for bridges with skew angles less than or equal to 20° and to undergo 3D finite element analysis whenever the skew angle is greater than 20°. (Trilok Gupta and Anurag Misra 2007), adopted grillage analogy method, based on stiffness matrix approach. They studied the skew effect on T-beam bridges with spans ranging from short to a medium having span and width of the same order. After research they concluded that grillage analogy method, based on stiffness matrix approach, is a reliably accurate method for a wide range of bridge decks and interestingly high positive and negative reactions develop close to each other for skew T-beams bridges, (Ibrahim S.I. Harba 2011), presented a parametric study which evaluated the effect of skew angle on the behaviour of simply supported R.C. T-beam bridge decks after comparing with normal/straight bridges. Study carried out by performing three dimensional finite element analysis for skewed T-beam bridge decks and recommended that beside disagreement with AASHTO and LRFD standard specifications for bridges even with skew angles less than 20° been designed as straight (non-skewed) bridges. (Nouri and Ahmadi 2011), demonstrated the skew angle effect using the 3-D FEA on the longitudinal bending moment and shear force, shear-distribution factor, the effect of transverse diaphragm arrangement, AASHTO LRFD Specifications in continuous composite girder bridges. The result showed that the moment and shear of exterior girders control the design and transverse diaphragms perpendicular to the longitudinal girders of the bridges are the best arrangement for load distribution.

Finite Element and Approximate Approach

(Sawko and Cope 1969) presented the benefits of the finite element method over the model testing, finite difference methods, and the grillage approach. Authors work also highlighted the Poisson ratio effects in their application of finite elements to orthotropic skew decks, with longitudinal stiffness greater than transverse stiffness. (Cousins and Besser 1980) evaluated a 45^0 skew angle slab with one end simply supported with semi-infinite rigidity reticent and other end having various discrete elastic supports. Their investigation was on the basis of skew bridge deck with particular focus on the obtuse corners and boundaries in determination of shear forces in the slab. Moreover, significant reversals were exposed in the study for bending moment near obtuse corners as well as the largest values of the torsional moment. (James A. Kankam and Habib J. Dagher 1995), developed non-linear analysis of RC skewed slab bridge with a specially written finite element program termed as NARCOS. It was revealed to get a higher crack initiation load or ultimate load carrying capacity provide a more reinforcement at obtuse corner as compare to the acute corner. (Miah Khasro and Kabir Ahsanul 2005), studied the RCC skew slabs behaviour under concentrated loads applied vertically. It has been suggested layered technique of finite element analysis is quite effective to estimate the ultimate load carrying capacity of the RC skew slabs. (Tande S. N. 2006), presented RCC skew slabs critical analysis for uniformly distributed, concentrated and patch loads with clamped edges. In order to derive higher accuracy results in evaluating bending, simplified finite strip approach was adopted. Effect of skew is also investigated. The results obtained are in reasonable agreement with those from the finite element. (Theoret et al 2012), Results of an investigation aimed at determining bending moments and shear forces, required to design skewed concrete slab bridges using the equivalent-beam method are presented in this paper. It has been shown that non-orthogonal grillages can be used to analyse the skewed slab bridges because that predict the amplitude and the transverse distribution of longitudinal bending moments and shear forces satisfactorily.

CONCLUSIONS

The author discussed the behaviour of skew slab bridges in the context of lateral Load distribution, skew angle effect and bending moment/ coefficient and deflection determination by using the various method, i.e., approximate analysis, Finite strip, grillage analogy and finite element method.

After study the research of various researchers. It can be concluded that:-

1. The elastic solutions for Skew slab bridges are available in the published literature as observed. The bending moment and deflection expression determined by various researchers for standard skew angle, i.e., 0^0 to 60^0 with specific load cases. These final expressions neither are used in routine practices for design calculations nor used in finite element based software in design offices. It is suggested prepare a bending moment coefficient for angle 0^0 to 90^0 for the ready reference for designer to design skew slabs
2. Most of the researchers have employed finite element methods to analyse the behaviour of skew slab bridges by using various software packages. but in present scenario these software packages wants high skill to operate and interpret the data to find out valid results, so it can be recommended that analyse the skew slab by the principal of limit analysis so it can be understood by designer easily.
3. Maximum work has been done to justify the AASTHO Code standard specification, but no work reported to if the slab is subjected to the odd type of loading and with or without opening. It has been strongly recommended by the

various researchers that to predict the accurate behaviour better to analyse a skew slab with three-dimensional finite element method.

4. The influence of support flexibility and obtuse/acute corner on the moment field induced in the slab warrants further investigation.

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