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Live Load Distribution of Road Construction: A Review

Akram Khan,
M.Tech Scholar, Department of Civil Engineering
Eklavya University, Damoh
Hariram Sahu,
Assistant Professor, Department of Civil Engineering
Eklavya University, Damoh
Dr. Anil Pimpalapure
Dean and Professor, Eklavya University, Damoh

Abstract

Live load distribution in road construction is a critical aspect of ensuring the structural integrity and safety of highway bridges. This abstract provides an overview of the key factors and methods involved in live load distribution for road construction, drawing insights from various research sources. Researchers have conducted experimental and numerical evaluations of Live Load Distribution Factors (LLDFs) proposed by organizations like the Indian road Congress Standard [1]. These LLDFs play a pivotal role in determining how the weight of vehicles and other dynamic loads is distributed across highway bridges. Studies have compared live load distribution methods adopted in different regions, such as British and American distribution factors (DF) for highway bridge analysis [2]. Understanding these international standards is essential for engineers working on road construction projects. Research has delved into live load distribution factors for skew stringer bridges, which are common in modern highway construction [3]. This knowledge is crucial for designing and assessing the safety of such bridges. Investigations have been conducted to determine LLDFs for both interior and exterior girders in horizontally curved bridges [4]. This addresses the unique challenges of curved road construction. This abstract provides a glimpse into the diverse aspects of live load distribution in road construction, highlighting the importance of research and standards in ensuring the safety and longevity of highway bridges. Engineers and professionals in the field must consider these factors when designing and assessing road construction projects.

Keywords: Live Load Distribution Factors (LLDF), LRFD, LFD, DF, IRC STANDARDS

1. Introduction

1.1 Live Load Distribution Factors

The live load distribution factors (LLDF) described in the IRC STANDARDS-LFD specifications had been used for more than 50 years prior to their update in the IRC STANDARDS-LRFD Bridge Design Specification. The formulas represented in IRC STANDARDS- LFD are based on the girder spacing only and are usually presented as S/D, where S is the spacing and D is a constant based on the bridge type. This method is suited to straight and non-skewed bridges only. While the formulas represented in IRC STANDARDS-LRFD are more useful and accurate since they take into account more parameters, such as bridge length, slab thickness, and number of cells for the box girder bridge typ. The change in IRC STANDARDS-LRFD equations has generated some interest in the bridge engineering world and has raised some questions. Skewed Bridges will be gained by using IRC STANDARDS-LRFD Specification [3].

Live load distribution factors enable engineers to analyze bridge response by treating the longitudinal and transverse effects of wheel loads separately. These factors have simplified the design process by allowing engineers to consider the girder design moment as the static moment caused by IRC STANDARDS standard truck or design lane loads, multiplied by the live-load distribution factor calculated through IRC STANDARDS LRFD, 4.6.2.2.2b [4]. Fig 1.1 shows the interior and exterior girders that carry the truck loads. The distribution factor decreases when the bridge shares and distributes the load efficiently among adjacent girders. This leads to a low design moment for a given truck size.

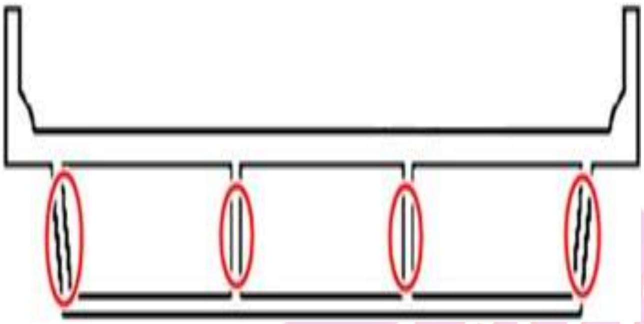

Figure 1.1: Interior and Exterior Girders that Carry the Design Vehicular Loads

Since 1931, live load distribution factors have been described in the Standard Specification for Highway Bridges. The early values have been updated and modified in 1930 by Westergaard and in 1948 by Newmark as new research results became available. The distribution factor presented in IRC STANDARDS Standard Specifications was S/5.5 for a bridge constructed with a concrete deck supported on pre-stressed concrete girders. This is applicable for bridges that carry two or more lanes of traffic, where S is the girder spacing in feet. This factor is applied to the moment caused by one line of wheels. Even so, some researchers such as Zokaie have noted that the changes in LLDF over the last 55 years have led to inconsistencies in the load distribution criteria in the Standard Specifications these include: inconsistent changes in distribution factors to reflect changes in design lane width; inconsistent consideration of a reduction in load intensity for multiple lane loading; and inconsistent verification of accuracy of wheel load distribution factors for various bridges [4].

In 1994, IRC STANDARDS LRFD Specifications recommended new load distribution equations as an alternative to the Standard Specifications. These distribution equations were derived from the National Cooperative Highway Research program (project 12-26). The formulas consider many bridge parameters including skew and continuity rather than limited parameters that were previously considered in IRC STANDARDS Specification. According to Zokaie, the new distribution factors lie within 5 percent of the actual distribution factors found by analyzing the bridge superstructure by using the finiteelement model. Although the distribution factor formulas in IRC STANDARDS LRFD are considered to be more accurate than the distribution factors in the Standard Specifications, some researchers like Chen and Aswad, have found that they are conservative, and they are uneconomical for bridges with large span –to- depth ratios. According to Chen and Aswad the conservatism of the distribution factors can be 18 to 23 percent for interior girders and 4 to 12 percent for exterior girders [4].

LRFD Article 4.6.2.2.2 presents live load distribution factor formulas for several common types of bridge superstructures. These distribution factors provide a fraction of design lanes that should be used to an individual girder to design it for moment or shear. The factors take into account interaction among loads from multiple lanes. Table 1.1 shows some types of bridge superstructures with equations of live-load distribution factors for moment in interior and exterior girders for different types of straight bridges. There are many other types of bridge superstructures listed in the IRC STANDARDS LRFD [1].

2. Literature Review

Bridge engineers have used the concept of distribution factors to estimate the transverse distribution of live loads since the 1930’s. The live load distribution for moment and shear is essential to the design of new bridges and to evaluate the load carrying capacity of existing bridges.

Big efforts have been made to develop and simplifythe live load distribution equations. Also, many researches have been conducted in order to determine the effect of certain parameters, such as girder spacing, span length, and skew angle. The literature review presented in this chapter summarizes past findings that are relevant to this project and will only cover the following areas: background about previous IRC STANDARDS specification and IRC STANDARDS LRFD, summary of relevant research studies, IRC STANDARDS LRFD development, and current IRC STANDARDS formulas for box Girder Bridge.

2.1 Background about Live Load Distribution Factor

The IRC STANDARDS-LRFD live load distribution formulas were derived from the National Cooperative Highway Research Program (NCHRP) 12-26 project and they were entitled ‘‘Distribution of Live Loads on Highway Bridges’’. This project was first proposed in 1985 to improve the accuracy of the earlier equations (S/D formulas) that were described in the Standard IRC STANDARDS specifications. Upon review of the S/D formulas, it was found that the S/D formulas were applicable to bridges having typical geometry. For example, the S/D formulas were generating valid results for bridges having girder spacing near to 6 ft and a span length of about 60 ft. However, the formulas needed to be revised and evaluated to get accuracy [4].

2.2 Previous Research Studies

2.2.1 Khaleel and Itani

In 1990, Khaleel and Itani studied the behavior of continuous slab-on-girderbridges subjected to the IRC STANDARDS HS20-44 truck loading with different degrees of skew. In this study, up to 112 continuous bridges were analyzed with five pre-tensioned girders using the finite element method. Varied parameters were taken into account including span length, skew angles, and spacing between the girders. The span lengths varied from 80-120 ft, the angles of skew varied between 0 and 60°, and the girder spacings ranged from 6-9 ft. Khaleel and Itani found that previous load distribution formulas in IRC STANDARDS Standard Specifications underestimated the positive bending moment for exterior girders by approximately 28%. The design moment was underestimated by 6-40 percent for an interior girder [9].

2.2.2 Zokaie, Osterkamp and Imbsen

This study focused on evaluating and developing methods for determining live- load distribution factors for several common bridge superstructure types. Different kinds of bridges have been considered in this study such as slab-on- beam bridges; multi–cell, box–girder brides; and multi-box beam bridges. To investigate the live load distribution factors for each bridge type, three methods of analysis were used for this purpose [10].

- Level 1 this method was considered to be the most accurate analysis, it included a determination of the live load distribution factors with a detailed finite element modeling of the bridge superstructure (deck). Different finite-element programs were used to analyze the bridges. Shell elements were used to model the deck for slab-on- beam bridges, and beam elements were used to model the girders.
- Level 2 In this method, design charts and grillages using grid models were used to calculate the live load distribution factors.
- Level 1 Based on Level 2 and 3 analyses, the analysis in level 1 used simplified formulas to calculate the live-load distribution factors. These formulas were found to be accurate as much as those in the level 2 and 3 analysis for their ranges of applicability. Correction factors were applied to the formulas to consider for the effect of girder location such as exterior or interior girder, skew and continuity as well.

The sensitivity of the live-load distribution factors was also studied for different bridge properties. The average bridge properties were varied for each bridge, and their effects on the distribution factors were analyzed and evaluated. Beam spacing was found to be the most significant property. Also, other parameters like span length, longitudinal stiffness, and transverse stiffness affected the distribution factors [4].

According to the Zokaie`s study in 1991, this research resulted in formulas (Level 1 analysis) for determining live-load distribution that are more accurate than those used in the previous codes. These formulas are simpler, easier to use and are approximately as accurate when compared with the methods used in the level 2 and 3 analysis.

Chen and Aswad.The main goal of this study was to revise and evaluate the accuracy of the formulas for live load distribution in the LRFD Specification in 1994 for modern pre-stressed concrete bridges made of I-girders or spread box girders with high span-to-depth ratios. The results of distribution factors obtained from simplified LRFD method were smaller than those obtained from IRC STANDARDS Standard Specifications for interior girders. [5].

The study that has been done by Chen and Aswad [6] showed that a refined method of analysis such as finite element analysis, could reduce the midspan moment for spread- box girder by 18-23% for interior girder and by 4-12% for exterior girder when compared to the IRC STANDARDS LRFD. A similar reduction was also shown to exist for I-girders. As a result of this study, it was recommended to use a finite element or grillage analysis for longer span bridges.

2.2.3 Shahawy and Huang

In this study the distribution factors determined first from finite element analyses and then compared to those obtained from IRC STANDARDS LRFD equations [1]. It was concluded that the methods presented in the Specifications for determining the live load distribution factors for bridges having two or more lanes loaded are satisfactory. However, if the girder spacing and deck overhang exceed 8 and 3 ft, respectively the errors of up to 30% could be expected. It was also concluded that the IRC STANDARDS LRFD load distribution factors for interior and exterior girders of two or more design lanes and for one design lane bridges are too conservative for strength evaluation and rating purposes [7].

2.2.4 Simth, D.

A series of parametric studies have been performed by Smith [8] to modify the live load distribution factor method for the Canadian Highway Bridge Design Code. This research study ended up with a distribution factor method based on dividing the total live load equally between all girders and then applying a modification factor based on the properties of the bridge, including span length, number of lanes loaded, girder location (internal vs. external), girder spacing, and width of the design lane. The new method then was compared to the distribution factor method from the 1996 version of the Canadian Highway Bridge Design Code. A separate modification factor is used for flexure and shear. In general, bridges are divided into two separate types: shallow superstructure and multi-spine bridges. Due to this study a set of equations was developed for flexure and shear for different types of bridges such as multi-cell box girders, slab bridges, and steel grid deck-on-girders [8].

2.3 Development of Distribution Factor in IRC STANDARDS LRFD

2.3.1 IRC STANDARDS-LRFD Specification

Since the IRC STANDARDS-Specification would not be accurate when the bridge parameters were varied (e.g., when relatively short or long bridges were considered), the additional parameters such as span length and stiffness properties must be considered in order to get higher accuracy. As a result, the original formulas were revised by Zokaie[3], to improve their accuracy when applied to the LRFD live loads. These formulas were developed by using several bridge types such as reinforced concrete T-beam, pre-stressed concrete I-girder, and steel I-girder, and multi-cell box girder. Then, their results were compared using an accurate method in order to evaluate the existing formulas. Finite-element or grillage analysis methods were used for this purpose, and bridge superstructure models were prepared based on geometric parameters and material properties. Then, analytical models were developed for several hundred actual bridge superstructures and the database was prepared for all of these bridges [4].

Zokaie conducted a study to evaluate the existing formulas using actual bridge super structure database to compare the results with the finite element results. The parameters study was also examined by Zokaie using the database to indentify the range and variation of each parameter. Then other procedures were followed to simplify the formulas [3]

2.3.2 Procedure of Determining LLDF in IRC

STANDARDS LRFD

To carry out a finite-element or grillage analysis of the bridge superstructure, several hundred actual bridge decks were prepared by Zokaie [3]. These bridges were selected randomly from the National Bridge Inventory File (NBIF) and bridge plans were obtained from the state departments of transportation. From those bridge plans many parameters were extracted and were stored in a database to be used in the study. The database contained information that included different types of bridge, span lengths, edge to edge widths, skew angles, number of girders, girder depths, slab thicknesses, overhangs, curb to curb widths, year built, girder eccentricities (distance from centroid of the girder to the mid-height of the slab), girder moments of inertia, and girder areas.

2.3.3 Identification of Key Parameters

The bridge database was studied by Zokaie [3], to classify the range and variation of each parameter. For each parameter, the maximum, minimum, average, and standard deviation was obtained. Several parameters were plotted against each other to determine if those parameters are correlated to each other. . For example, the girder spacing and slab thickness that are considered to be correlated to each other, or for larger span lengths that result in larger moments of inertia and/or girder depths. Also, Zokaie conducted a sensitivity study to identify which parameters have a significant effect on the live load distribution. To calculate the live load distribution factors for shear and moment, a bridge superstructure finite-element model was prepared for the average bridge and loaded with the HS20 truck. The longitudinal stiffness ($Kg = I + Ae^2$) parameter was introduced for the girder to cut down the number of variations. This parameter, ($Kg = I + Ae^2$), can replace the girder inertia (I), girder area (A), and girder eccentricity (e). Bridge decks with the same Kg and different I, A, and e values are found not significantly affected the final distribution factors.

A similar analysis was conducted by Zokaie [3] for several models by keeping all the parameters as average value, except for one that varied from its minimum to its maximum. The same process was repeated for all parameters to determine the keyparameters for each bridge type such as girder spacing (S), span length (L), girderstiffness (Kg), and slab thickness (t). Variation of truck axle width (gauge) was not considered because the design truck has a fixed gauge width. Most permitted trucks have a larger gauge width, which results in lower distribution factors. Therefore, using simplified formulas that are developed based on the design truck will produce conservative results for permitted trucks.

According to the sensitivity studies conducted both in the NCHRP 12-26 Project; girder spacing (S) was the most sensitive parameter in determining the live load distribution factors (LLDF). Span length (L) is the next most sensitive parameter and longitudinal stiffness (Kg) has less of an effect on the LLDF and slab thickness (t) appears to be least sensitive in computing the LLDF.

As a result of the sensitivity studies, some parameters were kept such as girder spacing and span length since they have a significant effect on LLDF. And other parameters eliminated from the new simplified LLDF equations such as the slab thickness and the longitudinal stiffness [11]. The longitudinal stiffness parameter (Kg) was found to be associated to the span length parameter (L) since the general trend of the relationship is that Kg increases as L increases.

2.4 Current IRC STANDARDS Formulas for Box Girder Bridge.

The equations developed in NCHRP 12-26 needed to be modified to be consistent with the LRFD specifications. Live load description and multiple presence factors are the two issues of particular importance in comparing the live load response calculation procedures of the IRC STANDARDS 16th edition and LRFD specifications. The live load truck in the IRC STANDARDS 16th edition consists of either an HS20 truck or a lane load; whereas, the live load in the LRFD is combination of both a HS20 truck and a lane load. Both trucks have a 6 ft axle width, which is the most important factor affecting the transverse distribution of live loads. Therefore, it was assumed that the difference in the live load configuration does not affect the live load distribution [3]. The formulas for different types of bridge superstructures such as concrete box girders, steel beam, and precast concrete I section needed to be revised to reflect this difference.

In order to apply the LRFD Specifications [1] to a cast-in-place multi-cell box bridge, the bridge must have a constant width; parallel beams with approximately equal stiffness; span length of the superstructure exceeding 2.5 times the width, and a central angle up to 34 degrees. These restrictions became the objective of a study by Song et al. [10]. A detailed study was conducted to investigate whether or not these limits could be extended to include most of the box-girder bridge designs in California. In general, the analysis results from this study indicated that the current LRFD distribution factor formulae for concrete box-girder bridges provide a conservative estimate of the design bending moment and shear force. Also, the results show that the LRFD formulae are more conservative when estimating design forces in the exterior girders, especially for shear forces.

3. Conclusion

In conclusion, the study of live load distribution in road construction is an integral and multifaceted aspect of ensuring the safety, reliability, and longevity of highway bridges. This review has explored various facets of this critical field, drawing insights from a range of research sources.

These evaluations help bridge engineers refine their understanding of how dynamic loads are distributed across structures, contributing to safer road construction practices. The comparison of live load distribution methods across international standards, such as those in British and American codes, underscores the need for a global perspective in road construction. Engineers must adapt to different standards to ensure consistency and safety in their projects.

The review has also shed light on the significance of considering specialized bridge types, such as skew stringer bridges and curved girder bridges. These structures require unique LLDF considerations to guarantee their structural integrity. The assessment of live load distribution factors for prestressed concrete girder bridges highlights the importance of material-specific analysis in road construction. Engineers must tailor their approaches to the materials used in bridge construction. The evolving IRC STANDARDS-LRFD Bridge Design Specification presents a significant shift in live load distribution factors, necessitating adaptation by professionals in the field to adhere to the latest industry standards.

In essence, the review underscores that live load distribution in road construction is a dynamic and evolving field that demands continuous research and adaptation to international standards. Engineers and professionals involved in road construction projects must remain vigilant, drawing upon the insights and findings of studies to ensure the safety and efficiency of highway bridges. With ongoing research and collaboration, road construction can continue to advance, offering safer and more reliable transportation infrastructure for the future.

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