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Developing girder distribution factors in bridge analysis through B-WIM measurements: An empirical study

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Abstract. The safety of bridges are critical in our transportation infrastructure. Bridge design and analysis require complex structural analysis procedures to ensure their safety and stability. One common method is to calculate the maximum moment in the girders to determine the appropriate bridge section. Girder distribution factors (GDFs) provide a simpler approach for performing this analysis. A GDF is a ratio between the response of a single girder and the total response of all girders in the bridge. This paper explores the significance of GDFs in bridge analysis and design, including their importance in the evaluation of existing bridges. We utilized Bridge Weigh-in-motion (B-WIM) measurements of five simple supported girder bridge in Indonesia to develop a simple GDF provisions for the Indonesia's bridge design code. The B-WIM measurements enable us to know each girder strain as a response due to vehicle loading as the vehicle passes the bridge. The calculated GDF obtained from the B-WIM measurements were compared with the code-specified GDF and the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) bridge design specification. Our study found that the code specified GDF was adequate or conservative compared to the GDF obtained from the B-WIM measurements. The proposed GDF equation correlates well with the AASHTO LRFD bridge design specification. Developing appropriate provisions for GDFs in Indonesian bridge design codes can provides a practical solution for designing girder bridges in Indonesia, ensuring safety while allowing for easier calculations and assessments based on B-WIM measurements.

Keywords: B-WIM; bridge analysis; bridge design; girder bridge; girder distribution factor

1. Introduction

Bridges play a pivotal role in connecting islands within countries like Indonesia, where geography poses unique transportation challenges. The establishment of robust bridge

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infrastructure is essential for enhancing connectivity, facilitating economic growth, and improving the overall quality of life for the population. However, ensuring the safety and reliability of bridges requires adherence to proper bridge loading codes. These codes provide guidelines and standards for determining the maximum loads that bridges can withstand, ensuring their structural integrity and preventing potential failures. Furthermore, the design phase of bridge construction is of utmost importance, as it involves meticulous planning and analysis to create structures that can withstand various forces, such as traffic loads, environmental factors, and potential natural disasters. By recognizing the significance of bridge infrastructure, adhering to proper loading codes, and implementing meticulous design practices, we can create a robust and resilient bridge network that fosters seamless connectivity and contributes to the sustainable development of regions and nations.

The current bridge code in Indonesia, SNI 1725:2016 (Badan Standardisasi Nasional 2016), represents a significant update from previous codes such as the Bridge Management System (BMS) 1992 and RSNI T-02-2005. It incorporates consensus-based revisions and integrates elements from overseas codes like the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications (USA), Eurocode 1: Action on structures EN 1991 (European Union), and Austroads AS Bridge Loading Code (Australia). However, one critical aspect missing from the current Indonesian code is provisions for Girder Distribution Factors (GDFs).

In the process of designing bridges, calculating the maximum moment in the girders is a pivotal step. Several methods can be employed for structural analysis, ranging from rigorous finite element modeling to simpler one-dimensional analyses utilizing GDFs. The inclusion of GDF equations streamlines this process, helping determine maximum girder moments efficiently. The absence of provisions for GDFs in the current Indonesian bridge design code is a significant gap. Accurate GDF knowledge is essential to prevent overestimations that could lead to costly repairs for deficient bridges. By addressing this gap, we can enhance bridge design accuracy, prevent economic burdens, and ensure safer and more cost-effective infrastructure.

In the AASHTO Standard Specifications (AASHTO 1996) there is a well-known distribution factor known as the "S-over" equation, primarily used for concrete slab on steel girder bridges with multiple design lanes loaded. Although these equations are generally straightforward to apply, they can lead to overestimation. Analytical studies conducted during the development of the AASHTO LRFD (Load and Resistance Factor Design) Code revealed that the GDFs specified by the AASHTO Standard Specifications are often inaccurate. In some cases, the specified values are overly conservative, while in others, they are too permissive (Eom and Nowak 2003).

The current AASHTO LRFD Bridge Design Specification (AASHTO 2012), introduces additional dependencies on the GDF equation based on the span length (L) and girder moment of inertia (Ig). The new LRFD specification significantly reduces the GDF compared to the traditional "S-over" distribution factor (Suksawang *et al*. 2013). However, bridge designers have encountered challenges due to the complexity of the GDF equations in the current specification. These equations involve unknown parameters until the girder selection stage, necessitating an iterative procedure. Therefore, there is a need for a more fundamental and simplified equation that can streamline the bridge design process.

The primary aim of this study is to more fundamental and simplified equations that align with Indonesian bridge design practices. This study aims to fill this gap by utilizing field testing, secondary data, and Bridge Weigh-in-Motion (B-WIM) measurements from various Indonesian bridges. Furthermore, the proposed GDF equation, will be recommended for inclusion in the

Indonesian bridge loading code, SNI 1725:2016. By incorporating the proposed GDF equation into the code, it will enhance the accuracy and reliability of bridge design and analysis in Indonesia.

This recommendation aims to address the current absence of provisions for GDFs in the existing code, ensuring that bridge structures in the country are designed with more precise and appropriate load distributions. The proposed GDF equation holds significant potential to contribute to the advancement of bridge engineering practices in Indonesia, leading to improved safety and performance of bridge structures.

2. Fundamentals of GDF

There have been several studies focusing on GDF, such as those conducted by (Puckett *et al.* 2015, Thakuria and Talukdar 2018, Kong *et al*. 2020, Zhang *et al.* 2021). These studies primarily investigate moment distribution factors. (Kim *et al*. 2021) proposed GDF equations based on ambient vibration testing. (Žnidarič and Kalin 2020) conducting investigations of Bridge Weigh-in-motion (B-WIM) to monitor GDF and influence lines. Another study by Suksawang *et al*. (2013) aimed to develop distribution factors for shear. The more recent study by (Choi *et al*. 2019) proposed set of equations of live load distribution factor for concrete box girder bridges. (Nowak and Eom 2001) and (Eom and Nowak 2003) conducted experimental investigations on GDFs for steel girders and found that the code-specified GDFs from AASHTO (American Association of State Highway and Transportation Officials) were adequate. They also observed that the distribution of live load moments tends to be more uniform for continuous bridges compared to simple span bridges.

The calculation of GDF involves determining the maximum strain experienced by each girder at the midspan position due to loading. According to (Sivakumar *et al*. 2008), the GDF is assumed to be the ratio of the static strain at a specific girder to the sum of all static strains across the girder. (Stallings *et al*. 1993) introduced the consideration of different section moduli (Si) of the girders by incorporating weighted strains. Consequently, the GDF for the ith girder can be expressed as follows:

$$GDF_i = \frac{M_i}{\sum_{j=1}^{k} M_j} = \frac{ES_i\varepsilon_i}{\sum_{j=1}^{k} ES_j\varepsilon_j} = \frac{\varepsilon_i w_i}{\sum_{j=1}^{k} \varepsilon_j w_j} \tag{1}$$

In Eq. (1), the variables are defined as follows: Mi represents the bending moment at the ith girder (kNm), E denotes the Young's Modulus of the girder (MPa), Si represents the section modulus of the i^{th} girder (m^3), ε_i represents the static strain at the bottom flange of the ith girder ($\mu\varepsilon$), wi represents the ratio of the section modulus of the ith girder to that of a typical interior girder, and k represents the number of girders. It is important to note that in this study, all girders have the same section modulus, resulting in equal weigh factors (wi) for all girders. Consequently, Eq. (1) simplifies to

$$GDF_i = \frac{\varepsilon_i}{\sum_{j=1}^{k} \varepsilon_j} \tag{2}$$

In the case of two lanes being loaded, the estimation of GDF is done by combining the strain data from single trucks due to traffic limitations. According to (Eom and Nowak 2003), the superposition of strains resulting from single trucks yields nearly identical outcomes as strains caused by trucks positioned side by side. It should be noted that when two or more lanes are loaded, the GDF values obtained from Eq. (1) need to be multiplied by the number of loaded lanes in order to align with the bridge code for comparison purposes. In Equation (1), the term "strain" can be substituted with other variables such as reaction force, deflection, or other considered responses, as suggested by (Restrepo 2002).

$$GDF_i = \frac{R_i}{\sum_{j=1}^{k} R_j} \quad (3)$$

where Ri represents the response of structural element at the i^{th} girder.

In this study, the GDF were primarily referenced from two design codes, namely AASHTO 96 and AASHTO LRFD 2012 (AASHTO 2012). The choice of AASHTO as a reference was driven by the absence of GDF provisions in the Indonesian bridge design code, SNI. However, it's important to note that SNI incorporates various aspects from AASHTO, such as loading combinations and other relevant parameters. The AASHTO 96 code utilizes the "S over" relationship to estimate GDF. These values serve as a foundational reference for understanding the distribution of live loads across the bridge's girders, a critical aspect of structural analysis and design. Specifically, for the bending moment in the interior girder, AASHTO 96 provides specified GDFs for girder bridges with one lane loaded as follows

$$GDF_i = \frac{S}{4200} \quad (4)$$

and for multi lanes loaded as

$$GDF_i = \frac{S}{3300} \quad (5)$$

where S is the girder spacing (mm).

The enhancements to the GDF equation were introduced in the AASHTO LRFD 2012 (AASHTO 2012) or AASHTO LRFD 2007 (AASHTO 2007) for the metric version. These improvements consider factors such as span length, deck stiffness, and bridge skew in order to determine the GDF. AASHTO LRFD 2012 provides specified GDF values for steel girder bridges with one lane as follows

$$GDF_i = 0.06 + \left(\frac{S}{4200}\right)^{0.4} \left(\frac{S}{L}\right)^{0.3} \left(\frac{K_g}{Lt^3}\right)^{0.1} \quad (6)$$

and for multi lanes loaded as

$$GDF_i = 0.075 + \left(\frac{S}{2900}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_g}{Lt^3}\right)^{0.1} \quad (7)$$

with S is girder spacing (mm), L is span length (mm), t is slab thickness (mm), and K_g is lateral stiffness (mm^4). The K_g value is given as follows

$$K_g = \frac{E_b}{E_d}(I_b + Ae_g^2) \quad (8)$$

with E_b represents the elastic modulus of the beam material (MPa), E_d represents the elastic modulus of the deck material (MPa), I_b represents the moment of inertia of the beam (mm^4), A represents the area of the beam (mm^2), and e_g represents the distance between the center of gravity of the beam and the deck (mm). It should be noted that in bridge cases, the third term $\left(\frac{K_g}{Lt^3}\right)$ in Eqs. (6) and (7) typically falls within the range of 0.85 to 1.10 (Phuvoravan 2006). For simplicity, a value of 1.0 is used in this study for the case of AASHTO LRFD 2014.

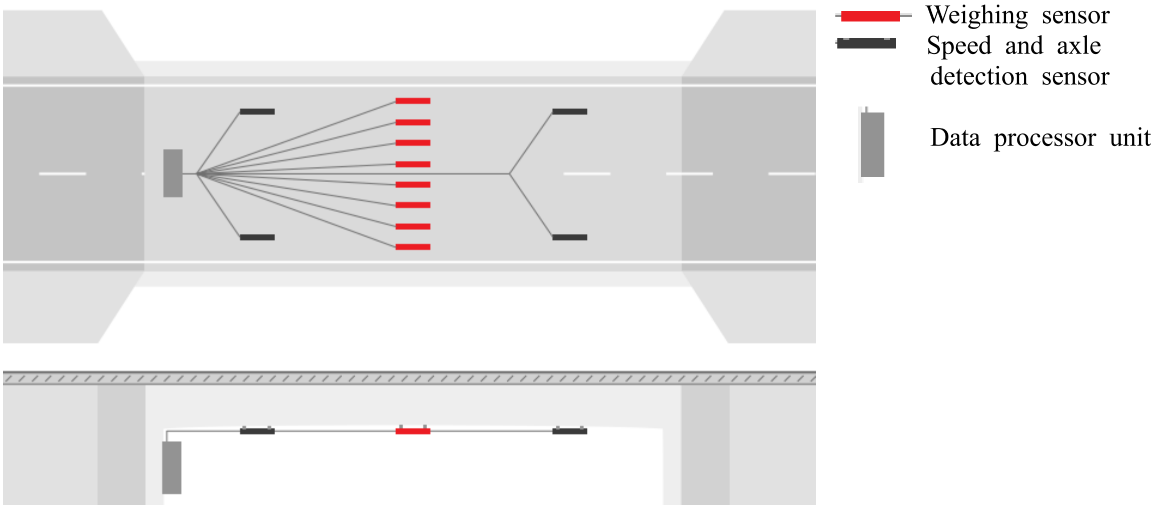

Fig. 1 Typical B-WIM system installation (CESTEL and ZAG Institute 2014)

3. Brıdge Weıgh-ın-Motıon (B-WIM)

B-WIM system is a cutting-edge technology that employs instrumented bridges or culverts to measure the weight of vehicles as they cross these structures. This system operates by capturing the dynamic response of the bridge due to vehicle movement. It utilizes strategically positioned sensors, particularly strain gauges, to monitor and record the bridge's dynamic behavior in response to the vehicles passing over (Nugraha *et al*. 2022). The collected measurements are then carefully analyzed and processed using Moses Algorithm (Moses 1979), to extract detailed vehicle data, including gross vehicle weight, axle weight, vehicle speed, and axle spacing. This comprehensive data enables engineers and researchers to gain valuable insights into the actual loads experienced by the bridge, aiding in the improvement of design standards, maintenance planning, and overall bridge performance assessment.

In our study, we adopted a typical B-WIM system sensor layout for girder and slab bridges, which is illustrated in Fig. 1. Within this layout, strategically positioned strain gauges are affixed at the mid-span of each girder's bottom flange, depicted as the red rectangle. These strain gauges play a crucial role in capturing the maximum strain induced by vehicles passing over the bridge, serving as weighing sensors for the B-WIM measurement system. The recorded maximum strains on each girder are then processed to determine the GDF. These GDF values are calculated by considering the ratio of the static strain at a particular girder to the sum of all static strains across the girders, aligning with the approach outlined by Anitori *et al*. (2017). This methodology allows us to accurately determine the GDF values, a critical component in our research on improving bridge design practices.

This research utilizes data from five active girder bridges in Indonesia that have been equipped with B-WIM systems. These bridges, detailed in Table 1, include Jembatan Cipeles, a steel composite girder bridge located in Sumedang, West Java; Jembatan Pawiro Baru A, a PCI girder bridge; Jembatan Pawiro Baru B, a steel composite girder bridge, both situated in Kendal, Central Java; Jembatan Kaligawe Railway Crossing, a PCI girder bridge in Semarang, Central Java; and

Bridge information:
Name: Pawiro Baru A
Bridge type: PCI Girder
Spacing of girders: 1.55 m
Length of span: 12.00 m
Number of girder: 6
Overhang width: 975 mm
Construction: 1994

B-WIM system information:
Sensor: Strain transducer
Sensor Spec: ST-503 IP65
Number of sensors: 6 for girder & 4 for slab
Hardware: Signal amplifier, cable, processor unit, power supply, router, traffic camera
Accuracy class: A(5)
Provider: Cestel SiWIM

Fig. 2 B-WIM system on Pawiro Baru A Bridge (Site ID001)

Table 1 B-WIM bridges detailed data

No	Bridge Name	Girder spacing (m)	Span Length (m)	Number of Girder	Overhang (mm)
1	Pawiro Baru A - PCI Girder	1.55	12.0	6	975
2	Pawiro Baru B - Steel CompositeGirder	1.75	12.0	8	125
3	Kaligawe Railway Semarang - PCI Girder	1.37	30.0	7	700
4	Padalarang Tollroad Exit - PCI Girder	1.65	16.5	14	275
5	Cipeles - Steel Composite Girder	1.50	29.6	6	750

Jembatan Padalarang Tollroad Exit, a PCI girder bridge in Bandung, West Java. The strain measurements gathered from these systems are used to determine the GDF. Among these bridges, we take a closer look at Pawiro Baru A Bridge, a notable example located in Kendal along the North coast of the Central Java national road, as illustrated in Fig. 2. This bridge, consisting of 6 Prestressed Concrete I (PCI) girders and spanning 12 meters as depicted on Fig. 2, has been instrumented for B-WIM measurements since 2017 and is classified as having an accuracy class A(5) for Gross Vehicle Weight (GVW) weighing according to COST323 (Laboratoire Central des Ponts et Chaussées 2002). Such comprehensive data from these bridge sites, including Pawiro Baru A, serves as the foundation for our research, enabling us to determine realistic GDFs and enhance the Indonesia’s bridge design code.

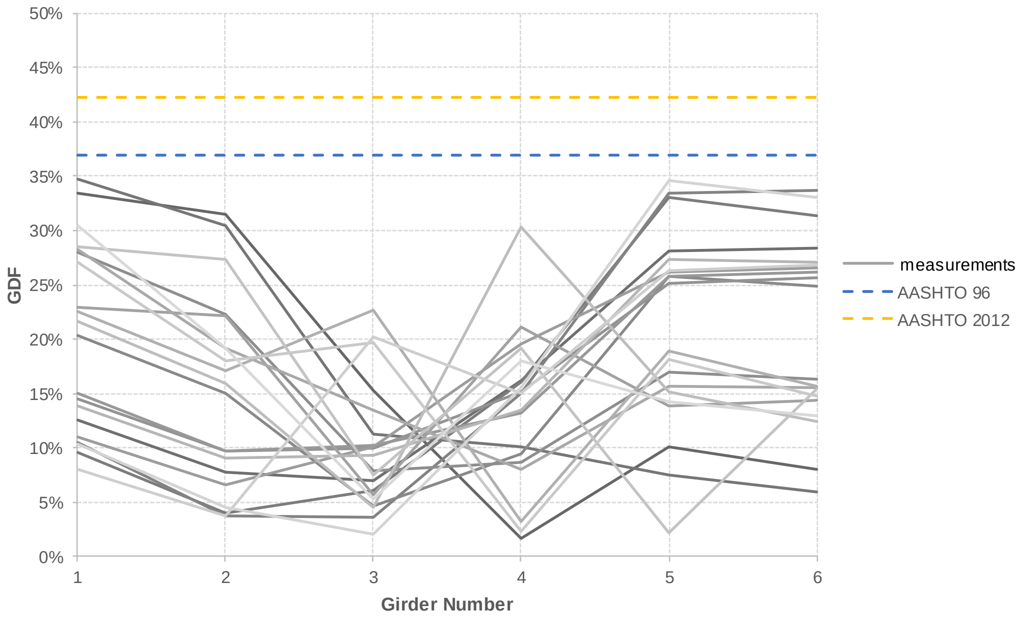

Fig. 3 GDF for single lane loading from B-WIM measurements (Pawiro Baru A Bridge, Site ID001)

4. Results and discussion

4.1 GDF from B-WIM measurements

This study relied on the utilization of five girder bridges in Indonesia equipped with B-WIM measurement system, and these bridges are listed in Table 1. Strain gauges were installed on each girder of these bridges to measure the structural response (strain) caused by vehicles passing over the bridges. The process of calculating GDFs involved collecting a substantial dataset. For each of the chosen bridges, a minimum of 20 measurements of structural response, captured under various vehicle loads, were diligently recorded. These measurements served as the foundation for GDF calculations, determined as the percentage ratio of the maximum strain recorded on an individual girder to the summation of maximum strains measured across all girders. This methodology was consistently applied to all six-girder bridges under examination.

For clarity and to provide visual insights into the GDF calculations, Figs. 3 and 4 exemplify the GDF outcomes derived from B-WIM measurements. Fig. 3 focuses on the GDF for single-lane loading on Pawiro Baru A Bridge (Site ID001), while Fig. 4 portrays the GDF for two-lane loading on the same bridge. The gray lines in both figures represent the distribution of strain measurements obtained from 20 different vehicle passages across the girders.

It's important to emphasize that the variation in vehicle load, position, speed, and other factors among the 20 vehicle measurements results in different strain distributions for each girder. This variation in strain distribution highlights the random nature of live load distribution on the bridge girders under real-world conditions. For instance, let's consider a specific vehicle from the ID001 B-WIM measurements used in this study, as illustrated in Fig. 5. This vehicle, a 32.21-ton 3-axle

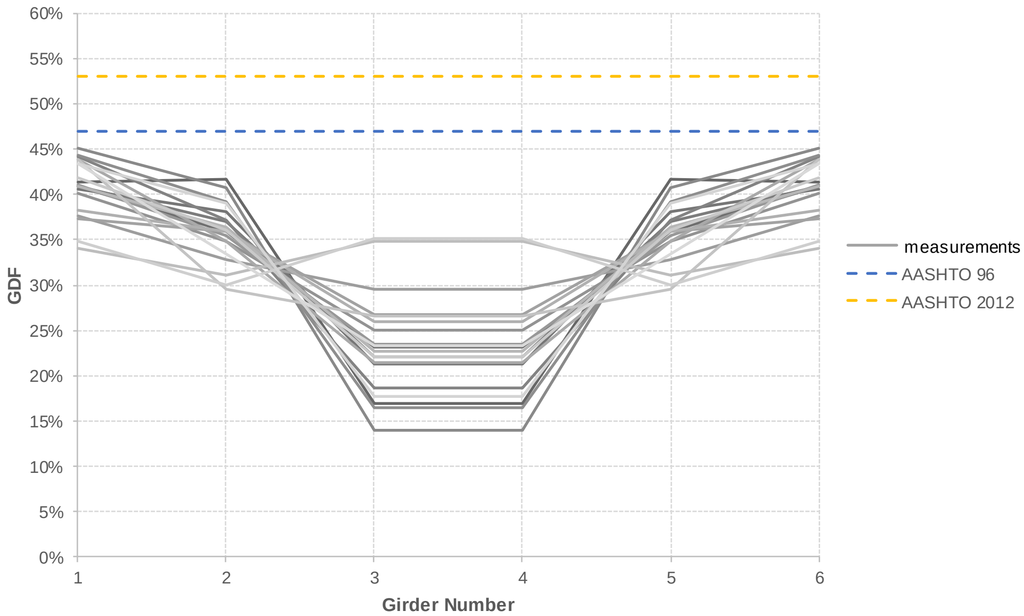

Fig. 4 GDF for two-lane loading (superposition) from B-WIM measurements (Pawiro Baru A Bridge, Site ID001)

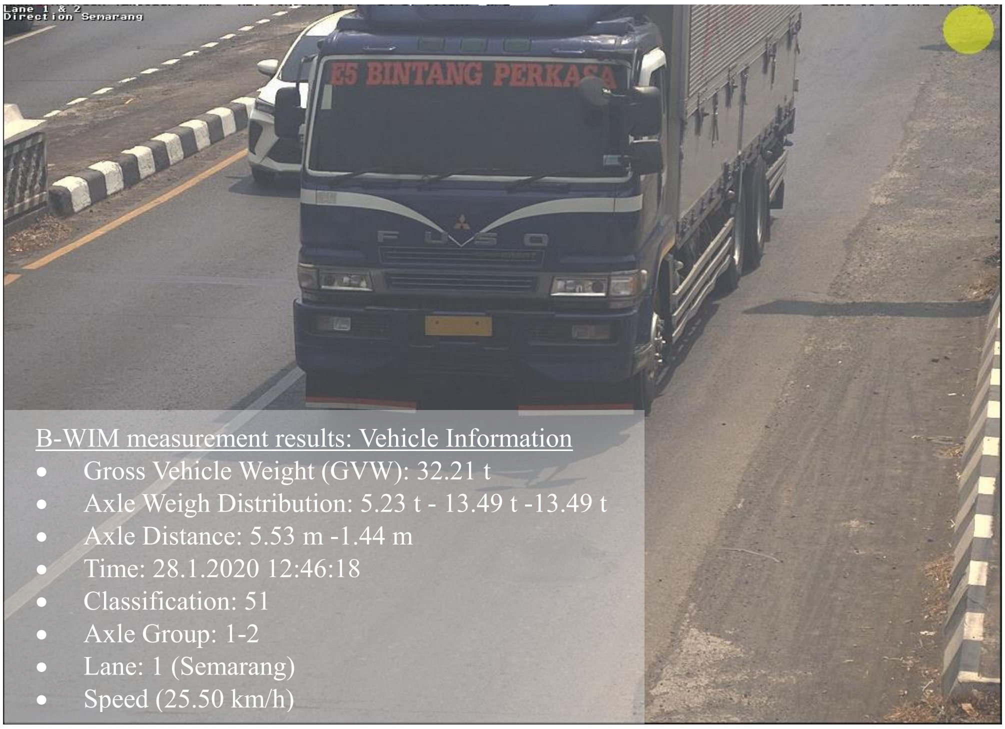

Fig. 5 Vehicle information from B-WIM measurements (Pawiro Baru A Bridge, Site ID001)

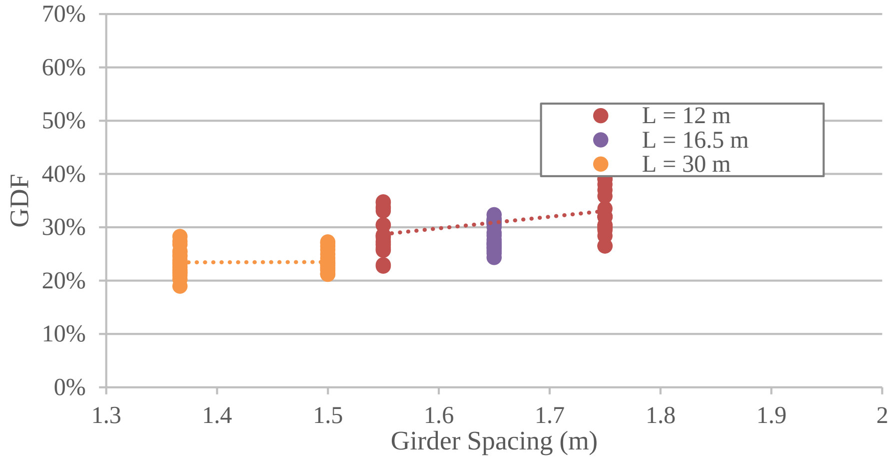

Fig. 6 Relationships between GDF and girders spacing for different span length, single lane loading

truck, was driving in the left lane over girders number 1 and 2, resulting in a unique strain distribution pattern displayed as the boldest gray lines in Fig. 3, representing the single-lane loading case. In the two-lane loading case, the results from Fig. 3 are mirrored on the adjacent lane and then combined, effectively simulating identical vehicle loading on both lanes, leading to the boldest gray lines in Fig. 4. This methodology was consistently applied to all 20 vehicle loading conditions, resulting in distinct strain distributions for each girder.

As Figs. 3 and 4 clearly reveal, the GDF value obtained from B-WIM measurements for these sample vehicles consistently fall below the GDF specified in the code. The yellow striped line represents the GDF for AASHTO LRFD 2012 (AASHTO 2012), while the blue striped line represents the GDF for AASHTO 96 (AASHTO 1996). For site ID001, the code proves to be sufficiently conservative for the design of a girder bridge when subjected to real loading based on B-WIM measurements. Notably, AASHTO LRFD 2012 exhibits higher GDF values and is more conservative than AASHTO 96.

As the number of girders varies among the selected bridges, as outlined in Table 1, presenting GDF data collectively for all bridges becomes impractical. To ensure clarity and precision, this study has opted to provide an illustrative example, with Site ID001 serving as a representative case. Subsequently, the GDF results for each bridge are meticulously calculated individually, acknowledging the unique characteristics of their structural responses and load distributions. Nevertheless, to provide a comprehensive understanding of GDF based on B-WIM measurements and to encompass the insights gained from all the bridges under consideration, this study intends to consolidate the results.

4.2 Proposed GDF equation

In this study, a new formula for the GDF equation is developed based on B-WIM measurement data from five girder bridges. The aim is to simplify the GDF calculation by considering only the girder spacing, similar to the approach used in AASHTO 96 GDF formula. This simplification is justified by the limited influence of the bridge span on the GDF, as demonstrated in Fig. 6. Fig.6 presents the relationship between girder spacing, span length, and the GDF, utilizing combined

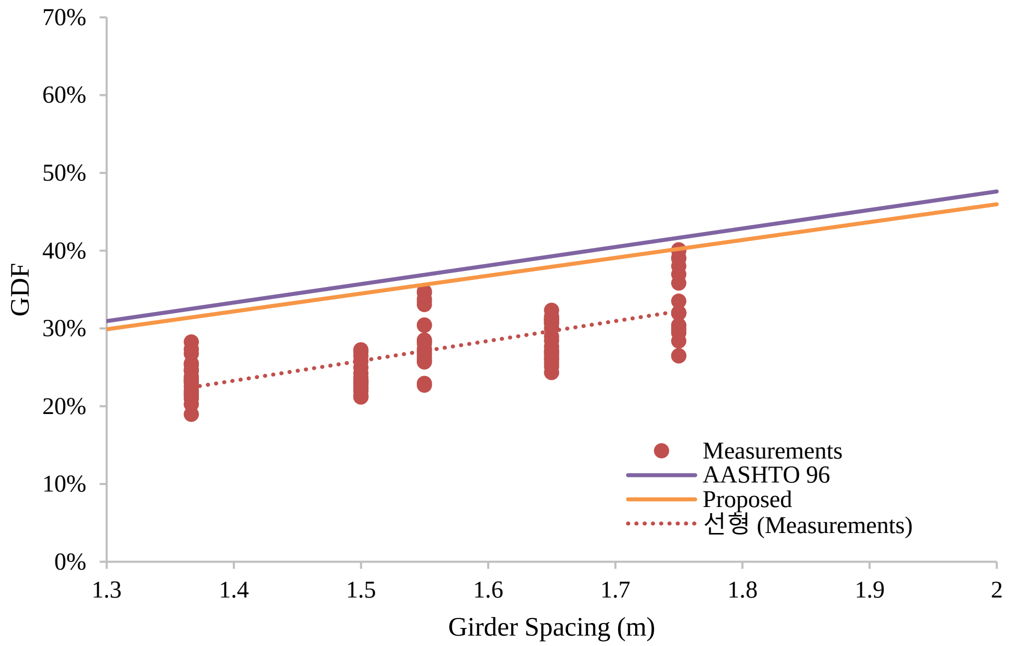

Fig. 7 Relationships between GDF and girders spacing, single lane loading

GDF data from B-WIM measurements across the five bridges. From the graph, it is evident that the span length has a minimal impact on the GDF. This finding aligns with the study by (Suksawang *et al*. 2013), which also observed a strong dependence of shear GDF on the girder spacing.

A total of five girder bridges were utilized in this study, as indicated in Table 1, with each bridge serving as a B-WIM system in Indonesia. These bridges are operated by the Ministry of Public Works and Housing for National Road bridges and PT Jasamarga Tollroad Operator for Tollroad bridges. The relationships between the GDF and girder spacing were examined for single lane loading in Fig. 7, and for two-lane loading in Fig. 8. In these figures, the maximum GDF for each bridge under vehicle loading is represented by red dots, while the dashed red line depicts the linear trendline of the data. The purple dashed line represents the AASHTO 96 GDF formula, and the yellow dashed line represents the proposed GDF formula for the Indonesian Bridge Code (SNI). Initially, a linear regression analysis was employed to examine the relationship between GDF and girder spacing. However, it was observed that many GDF values exceeded the regression line, suggesting the potential for underdesigned girders.

Given that the existing bridge code operates on LRFD principles, it's crucial to propose a GDF formula that aligns with this approach and accounts for the variable nature of GDF. To accommodate this variability, we've devised a method. We calculate the proposed GDF values by starting with the mean GDF variables and then adding a certain multiple of their standard deviation. This ensures a probability of non-exceedance 95%. Our research showed that for single lane loading, a multiplying factor of 2.5 times the standard deviation is appropriate. For two-lane loading, a factor of 2 achieves the desired 95% probability of non-exceedance. This difference

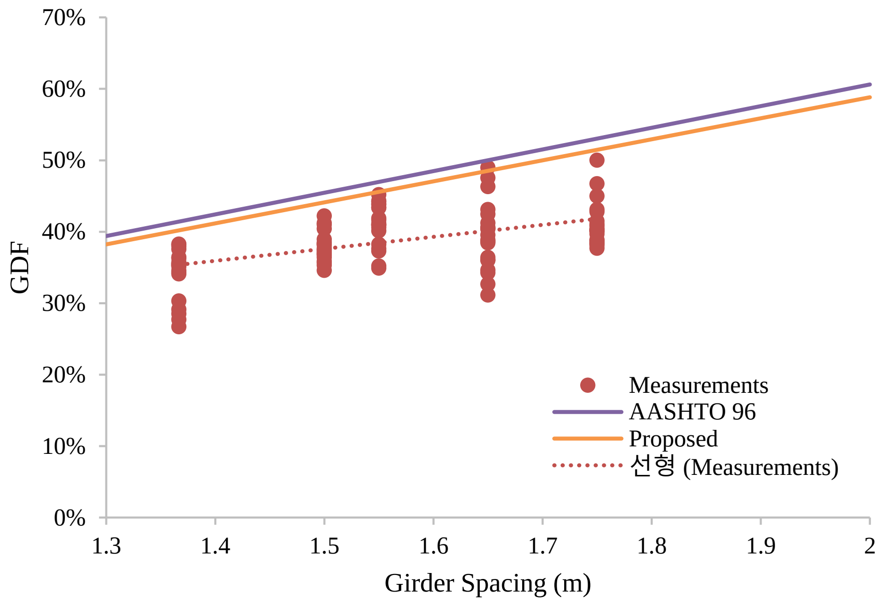

Fig. 8 Relationships between GDF and girders spacing, two-lane loading

arises because single lane loading tends to have a higher standard deviation but a more spread-out distribution. As a result, a larger multiplying factor is necessary to maintain the desired probability of non-exceedance. The resulting GDF formulas, customized for the Indonesian bridge code, are presented as Eq. (9) for single lane loading and Eq. (10) for two-lane loading. These formulas offer a practical and reliable way for engineers to design girder bridges, considering the probabilistic nature of GDF and adhering to LRFD principles.

$$GDF_i = \frac{S}{4350} \tag{9}$$

$$GDF_i = \frac{S}{3400} \tag{10}$$

Our proposed GDF formulas, outlined in Equations 9 and 10, were built upon the foundation of the AASHTO 96 S-over GDF formula. However, modifications were essential to account for the inherent variability in GDF variables observed through measurements, portraying a characteristic of a random variable. Through careful numerical calculations, we determined that a factor of 4350 for one lane loading and 3400 for two-lane loading were appropriate to achieve a probability of non-exceedance of 95% within the GDF distribution. These adjustments were crucial to ensure the GDF formulas aligned with LRFD principles and provided a balanced approach, steering clear of unnecessary conservatism. The primary objective of our study was to offer engineers in Indonesia a simplified GDF provision tailored specifically for girder bridges, enhancing the efficiency and accuracy of bridge design based on real GDF measurements. By incorporating this new formula into the Indonesian Bridge Code, engineers can access a more streamlined and precise method for designing simple girder bridges while considering the probabilistic nature of GDF as random variables, in harmony with LRFD principles.

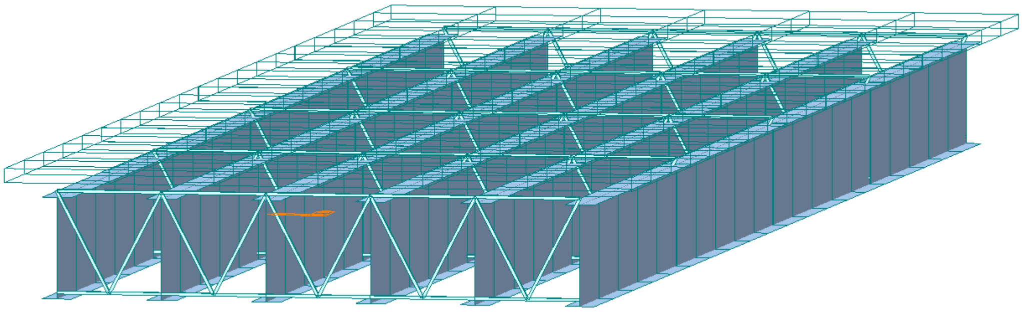

Fig. 9 3D view of the steel composite girder bridge designed with proposed GDF formula

4.3 Application of the proposed GDF formula

To demonstrate the application of the proposed GDF formula for the Indonesia Bridge Code, let's consider the design of a steel composite girder bridge, displayed on Fig. 9. The bridge has a span length of 30 meters, a deck width of 9 meters, and is simply supported. It consists of 6 girders with a spacing of 1.5 meters. The design scenario involves two-lane loading, following the standard loading specified in the SNI 1725 2016 Bridge Loading Code (Badan Standardisasi Nasional 2016). This includes a uniform dead load (UDL) of 9 kN/m^2 and a knife equivalent load (KEL) of 49 kN/m at the mid-span.

Using the GDF method derived from the proposed formula in this study, we can calculate the maximum moment in the girder and proceed with the design of the steel girder section. Considering the given bridge properties, we can calculate the loading by multiplying the UDL by the bridge deck width of 9 meters, resulting in a UDL of 81 kN/m. Similarly, the KEL results in a point load of 441 kN at the mid-span.The maximum moment due to the design live load of the UDL and KEL can be calculated using the formula $M_L = \frac{1}{8} \; q_{UDL} \; L^2 + \frac{1}{4} \; P_{KEL} \; L$. Plugging in the values, we have $M_L = 9112.5 \text{ kNm} + 3307.5 \text{ kNm} = 12420 \text{ kNm}$.

Using the GDF formula for two-lane loading, as given in Eq. (10), we can calculate the moment for one girder by assuming it contributes the most to the bridge's response under loading conditions. The GDF value is determined as S/3400 = 1500/3400 = 44.12%. Thus, the maximum moment due to the design live load for one girder is 44.12% x 12420 kNm = 5479.41 kNm. With this quick calculation of the live load moment, we can define a suitable steel girder section. Further detailed analysis, taking into account other forms of design loads such as dead load and superimposed dead load, can be carried out more efficiently and swiftly.

5. Conclusions

In conclusion, this research has undertaken an investigation into the Girder Distribution Factors (GDF) for girder bridges in Indonesia, addressing the absence of GDF provision in the Indonesian Bridge Code (SNI), by utilizing B-WIM measurements. The study has examined the GDF values by comparing them with the specifications provided in AASHTO 96 and AASHTO LRFD 2012. Notably, the findings have shown that the measured GDF values from B-WIM measurements consistently fell below the specified GDF values in the codes, signifying the adequacy of the code-specified GDF for the selected girder bridges.

Moreover, the influence of span length on GDF values was explored, revealing distinct patterns. AASHTO 96, which considers primarily girders spacing, yielded higher GDF values for shorter span bridges like the Pawiro Baru A Bridge. Conversely, AASHTO LRFD 2012, incorporating both span length and girders spacing, led to lower GDF values for longer span bridges like the Cipeles Bridge. However, it's essential to reiterate that the measured GDF values consistently remained below the code-specified GDF values, reinforcing their sufficiency for the bridges examined.

To address these findings and enhance local bridge design practices, a proposed GDF formula for the Indonesian Bridge Code, SNI, was developed. This formula, rooted in the principles of AASHTO 96 while considering the probabilistic nature of GDF, resulted in lower GDF values compared to the AASHTO 96 codes. Nevertheless, these lower values consistently aligned with the measured GDF values from B-WIM measurements, as evidenced by their close correspondence in graphical representations.

In summary, while our study has primarily focused on simplified cases of bridge design, it underscores a pivotal step toward advancing the understanding and utilization of GDF in Indonesian bridge engineering. Our work stands as a foundational effort, offering a practical, simplified, and alternative approach for designing girder bridges in Indonesia while adhering to LRFD principles and recognizing the probabilistic nature of GDF. It is crucial to recognize that our study is a starting point, paving the way for future research endeavors to expand upon these findings by considering a broader array of parameters and encompassing various bridge types. This collaborative effort within the engineering community holds the potential to refine and augment the GDF provision for more diverse bridge scenarios, thus contributing to safer, more efficient, and resilient bridge infrastructure in Indonesia.

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