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Optimal transverse position for overweight trucks to cross simply supported multi-girder bridges

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Abstract

Recent years has witnessed a steady increase in the issued overweight vehicle permits. Damage and deterioration of bridges caused by overweight vehicles have received increasing attention. Most previous studies on overweight vehicles have focused on the routing and weight regulation of overweight trucks while little attention has been paid to the determination of the optimal transverse position for overweight trucks to cross highway bridges. This article aims to investigate the optimal transverse position for overweight trucks to cross the simply supported multi-girder bridges and provide suggestions for the management of overweight vehicles. Finite element analysis is performed for a group of prefabricated concrete bridges commonly used in China under the action of overweight trucks with varying transverse positions, and the optimal transverse position is determined based on the maximum bending stress of the girders. The effects of a few important factors, including the superstructure configuration, length of bridge spans, number of girders, type of girder connections, and support conditions, on the optimal transverse truck position are also investigated. The findings in this article highlight the importance of the transverse position of overweight trucks when crossing multi-girder bridges.

Keywords

finite element analysis, multi-girder bridges, overweight regulation, overweight trucks, transverse loading position

Introduction

Recent years has witnessed a steady increase in the heavy truck traffic volumes and issued overweight vehicle permits (Fiorillo and Ghosn, 2016; Fu et al., 2012; Ghosn et al., 2015; Zhao and Tabatabai, 2012). Both the government agencies and the public have expressed considerable concern over the damage and deterioration of bridges due to increasing volumes of heavy truck on the highways. In addition, the regulations of overweight vehicles have also received a substantial amount of attention in recent years. Fu and Hag-Elsafi (2000) developed a checking method for overload permitting in the load and resistance factor format. Ghosn (2000) presented a reliability-based method for determining the optimal allowable traffic loads on bridges by considering the static and dynamic load effects. Adams et al. (2002) designed a system for finding viable routes for oversized/overweight vehicles while taking the spatial and temporal roadway restrictions into consideration. Vigh and Kollár (2006, 2007) proposed a fast and robust procedure for the routing and permitting of overweight trucks which sets restriction that the overweight truck should cross the bridge along a given path. Yin (2012) and Zong (2003) suggested that overweight vehicles should go along the centerline of bridges, but no detailed analysis was conducted regarding the optimal transverse loading position. Most of previous research works were focused on the routing and weight regulation of overweight vehicles. The optimal transverse position for overweight vehicles on bridges has received much less attention even though the transverse truck position has a remarkable influence on the bridge responses (Kim et al., 2013; Vigh and Kollár, 2007).

The regulation of highway transportation management for overweight vehicles proposed by the Ministry of Transport of the People's Republic of China (MOT) (2000) specified that overloading trucks must go along the centerline of bridges at a speed no faster than

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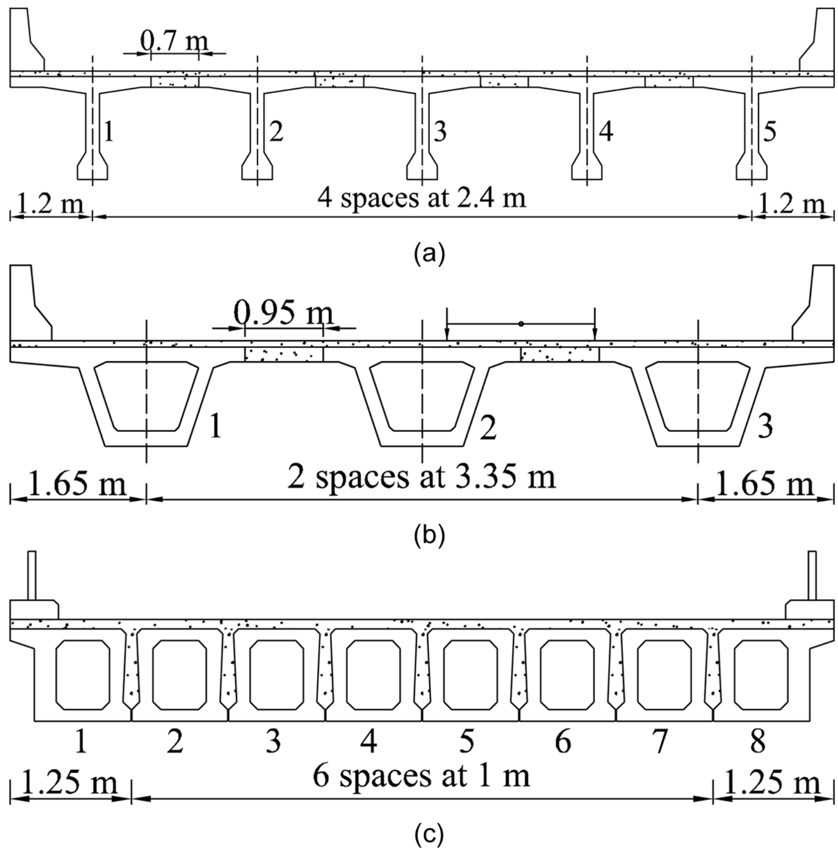


Figure 1. Cross sections of the bridges considered: (a) T-beam bridge, (b) box-beam bridge, and (c) voided-slab-beam bridge.

5 km/h when crossing bridges. However, few studies have been conducted to validate the rationality of this specification.

The objective of this study is to investigate the optimal transverse position for overweight trucks to cross simply supported multi-girder bridges and provide suggestions for the management of overweight vehicles. A group of typical prefabricated concrete bridges with different configurations were first selected. Next, the optimal transverse position for overweight trucks was determined based on the maximum bending stress on the bridge girders obtained from finite element analysis. Then, two typical loading cases were defined and compared to quantify the relative differences (*RD*s) between the regulations of the MOT and the suggestions in this study. Finally, the influence of superstructure configuration, bridge span length, number of girders, type of girder connections, and boundary conditions on the optimal transverse truck position was investigated.

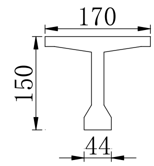
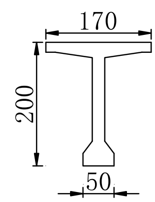
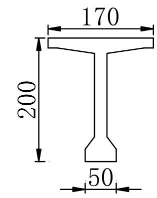
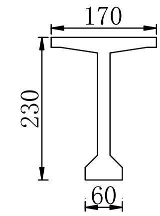
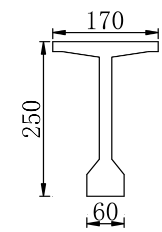
Properties of selected bridges

A group of typical prefabricated concrete bridges with different configurations were selected and analyzed. Three different types of superstructures widely used for short-to-medium-span bridges in China were considered. For the purpose of illustration, Figure 1 shows the cross sections of three bridges with different superstructures considered in this study. As can be seen, the first bridge is composed of five concrete T-girders spaced at 2.4 m, the second bridge consists of three concrete box-girders spaced at 3.35 m, and the third bridge has eight 1-m-wide concrete voided-slab-girders. The adjacent girders of all the bridges were connected by cast-in-place concrete joints. The span lengths of the three types of bridges were set to 20 m. However, in order to figure out the effect of span length on the optimal transverse truck position, five different span lengths for the T-beam bridge were investigated, that is, 20, 25, 30, 35, and 40 m. The dimensions of the cross sections for the T-beam bridges with different span lengths are shown in Table 1. End diaphragms were used for all bridges considered.

Overweight truck

According to a survey of traffic data at more than 60 sites in China (Zhang, 2014), the composition of

Table 1. Dimensions of cross sections for bridges with different span lengths.

Span (m)	20	25	30	35	40
Cross-sectional dimensions (cm)					

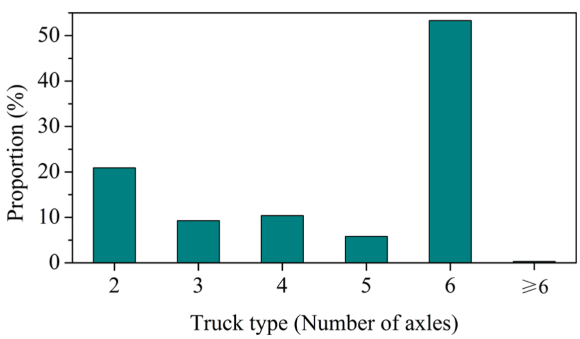


Figure 2. Composition of freight vehicles based on the number of axles.

freight vehicles, based on the number of axles, on highway bridges is illustrated in Figure 2. As can be seen from Figure 2, the majority of the freight vehicles are six-axle trucks. Based on the survey results, a representative overweight truck was chosen with axle configuration and weight distribution as shown in Figure 3. The gross vehicle weight (GVW) of the truck was set to 63.1 t, which corresponds to the mean value of the 95th percentiles of the GVW data from all observation sites, while the legal weight limit in China for six-axle trucks is 49 t (Standardization Administration of the People's Republic of China (SAC), 2004). The axle weights of the representative truck were determined based on the results from a regression analysis of over 200,000 weigh-in-motion (WIM) data.

Analysis method

The load effects of bridges can be calculated using either simplified methods, such as the beamline method which is one of the most widely used method, or more complicated methods, such as the three-dimensional (3D) finite element analysis method. The beamline method calculates the load effect by analyzing the bridge as a single beam and multiplying the load effect at the cross section under consideration by a girder distribution factor (GDF), as shown in the following equation

$$F_i = F_{\text{beamline}} GDF_i \tag{1}$$

where F_i is the load effect of the ith girder, F_{beamline} is the load effect in a single beam subjected to the vehicle load, and GDF_i is the distribution factor of the ith girder.

Although the beamline method is very efficient, it is argued to be too conservative and may result in lower bridge ratings and improper permit checking (Wood et al., 2007). It is widely accepted that the finite element analysis method, although being more time-consuming, can be more accurate in predicting the flexural behavior of bridges (Ding et al., 2012; Li et al., 2017; Yousif and Hindi, 2007). In order to investigate the optimal transverse position and quantify the differences between different loading cases, the finite element analysis method was therefore adopted in this study.

Finite element analysis

Finite element model

The finite element method was used to investigate the optimal transverse position of moving overweight trucks on multi-girder bridges. The ANSYS 15.0 (n.d.)

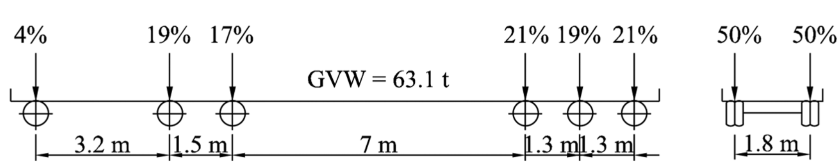


Figure 3. Characteristics of the representative overweight truck.

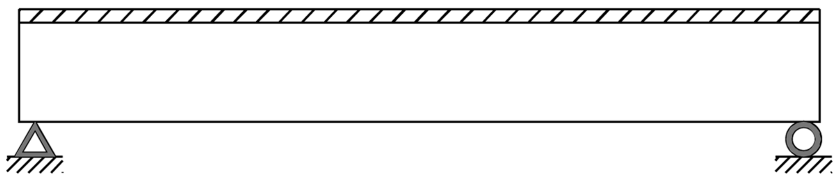


Figure 4. The bridge boundary conditions.

program was used to create the bridge models and to perform the structural analysis. The concrete bridge components, including the girders, deck, and end diaphragms, were modeled using SOLID45 elements. This element has three translational degrees of freedom at each node. The bridge girders were simply supported with a hinge at one end and a roller at the other end, as shown in Figure 4. Truck loads were applied at the wheel–bridge contact locations as point loads. Dynamic effect was not considered as the overweight vehicles were assumed to cross the bridge at very slow speeds. It was assumed all bridges remained in their linear elastic range under the action of truck loads for the reason that the behavior of bridges can be described by linear elastic models with sufficient accuracy under routine traffic conditions (with regular heavy trucks) (Eom and Nowak, 2001; Gheitasi and Harris, 2015). It should be noted that the accuracy of the finite element analysis results was verified in the previous research work of the authors (Yan et al., 2017) by comparing the analysis results with the results provided by Hays et al. (1995) using the benchmark provided in their study.

In the bridge models, two types of girder connections were used to account for the possible deterioration of the cast-in-place concrete connections. In practice, under the combined action of vehicle loads and environmental attack, girder connections will deteriorate and their condition is usually somewhere between the ideal rigid connection and ideal hinge connection (Chen, 2011; Xu, 2009). Therefore, in this study, rigid connections were adopted to simulate intact girder connections while hinge connections were used to simulate severely deteriorated girder connections. The rigid connections were modeled by coupling the nodes at the same location in the finite element model, while the hinge connections were modeled by coupling the translational degrees of freedom of the nodes at the top flanges of the T-girders, which was also adopted by other researchers such as Chen (2011) and Xu (2009).

Critical loading positions

A preliminary analysis found that barriers had a negligible influence on the optimal transverse position for moving trucks. As a result, in the following study, barriers were not considered. The cases with rigid connections between the adjacent girders were first investigated. In the longitudinal direction, the most unfavorable truck loading position for the bending stress at the bridge midspan was selected by utilizing the influence line. This was achieved by moving the truck loads step by step, at a distance of 0.2 m each step, in the longitudinal direction to obtain the maximum bending stress at the bridge midspan. In the transverse direction, the allowable range for the transverse truck position was defined, as shown in Figure 5. An edge distance of 1 m was assumed. Since the bridge is symmetric about the centerline, only the cases with the truck load applied to half side of the bridge were investigated. The cases with the truck load applied to the other half of the bridge was unnecessary due to the symmetry of the bridge. It should be noted that this study only considered the case with only one overweight truck permitted on the bridge, which agrees with the common practice.

In the finite element analysis, in order to determine the optimal transverse position for the truck, the truck was set to move within the allowable range step by step, at a distance of 0.2 m each step, in the transverse direction. Under each truck loading position i, static analysis was performed, and the maximum bending stress of all the girders, E_i, was obtained. To better illustrate the effect of truck loading position on the bridge response, a term named "relative bending stress" was defined as follows

$$E_{\text{relative}} = \frac{E_i}{E_{\min}} \tag{2}$$

where E_{relative} is the relative bending stress, E_i is the maximum bending stress of the critical girder under truck loading position i in consideration, and $E_{\min}$ is the minimum value of all the E_i obtained for different transverse truck positions. It should be noted that the maximum bending stress E_i may occur at different girders under different truck loading positions. Due to the definition of the relative bending stress, E_{relative} is expected to be no less than 1 for all possible transverse truck positions. The transverse truck position where E_{relative} equals 1 is actually the optimal truck loading

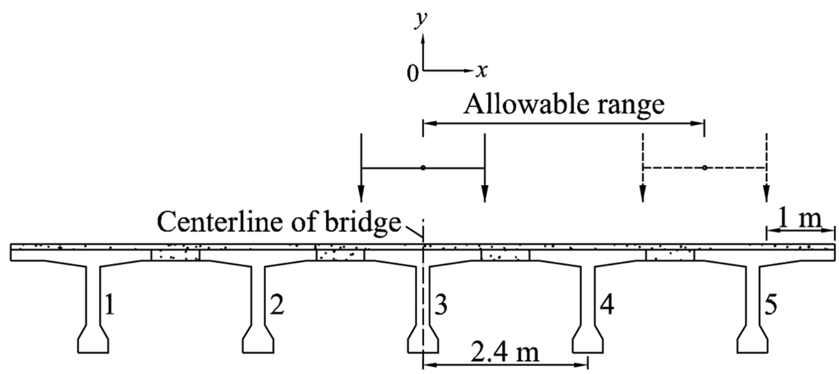


Figure 5. The allowable range for transverse truck position.

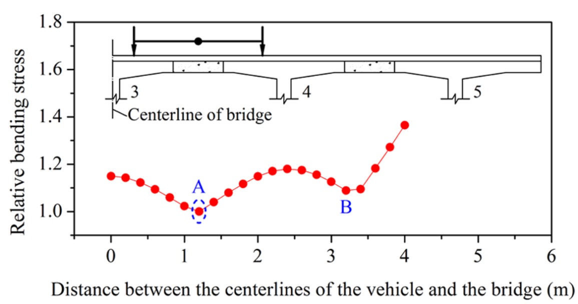


Figure 6. Variation of relative bending stress with change of truck transverse position.

position to minimize the maximum bending stress on the bridge girders.

For the purpose of illustration, Figure 6 shows the relative bending stress of the 20-m T-beam bridge. As can be seen from Figure 6, when the truck was positioned at the center of the bridge (the left-most point in Figure 6), Girder 3 was the critical girder which carried the majority of the truck load. When the truck started to move to the right, more load was shared by Girder 4, and the load carried by Girder 3 was decreased. When the truck moved to the top of the fixed joint between Girder 3 and Girder 4, the maximum truck load carried by a single girder reached the minimum and therefore the relative bending stress reached the minimum value of 1. As the truck moved further to the right, the load carried by Girder 4, which became the critical girder, was increased, leading to an increase in the relative bending stress. When the truck moved further to the right, more load was shared by Girder 5, leading to a decrease in the load carried by Girder 4 and therefore a decrease in the relative bending stress, which continued until the moment when the truck center moved to point B. As the truck kept moving right, the load carried by Girder 5, which became the critical girder, increased significantly, leading to a fast increase in the relative bending stress until the truck reached the edge of the allowable range. Similar results were observed on bridges with different span lengths, and the results are not shown here for the sake of brevity.

Comparison between two typical loading cases

Based on the results from the analysis of the bridge with five T-girders in the previous section, it was found that the middle of two adjacent interior girders was the optimal transverse position for the overweight truck to cross the bridge. The MOT in China suggests that overweight trucks should go along the centerline of the bridge slowly when crossing bridges. In order to verify the rationality of this specification, the bridge bending stress under these two transverse truck positions are investigated and compared in this section. For the purpose of convenience, the case in which the overweight truck is placed at the centerline position of the bridge will be referred to as Load Case 1 while the case in which the transverse position of the overweight truck leads to the minimum relative bending stress among all possible transverse truck positions will be referred to as Load Case 2. For the purpose of comparison, an *RD* is defined as follows

$$RD = \frac{R_1 - R_2}{R_2} \times 100\% \qquad (3)$$

where R_1 is the maximum bending stress of all bridge girders under Load Case 1 and R_2 is the maximum bending stress on all bridge girders under Load Case 2.

Based on the definition by equation (3), a positive value of *RD* means that the transverse truck position in Case 2 causes smaller bending stress on the critical girder than the case when the truck crosses the bridge along the centerline of the bridge. If this happens, the centerline of the bridge is not the optimal transverse

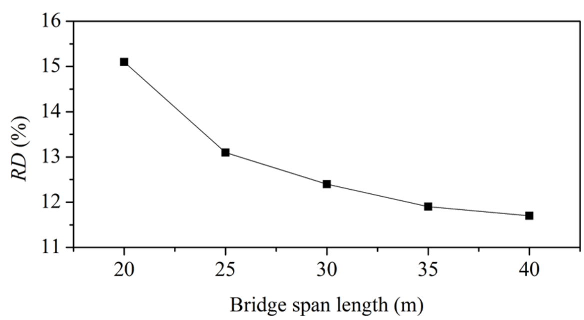


Figure 7. Relative difference in bridge response between the two loading cases.

truck position from the perspective of minimizing the maximum bending stress on the bridge girders.

Figure 7 plots the *RD*s in responses for the T-beam bridges with five girders and different span lengths. It can be seen from Figure 7 that the bending stress under Case 1 is larger than those under Case 2 for all the bridges considered, indicating that the centerline of the bridge is not the optimal transverse position for overweight trucks to cross the bridge for the bridges considered. It is also found that the *RD* decreases as the bridge span length increases.

Parametric study

In the previous section, the optimal transverse position for overweight trucks to cross highway bridges was analyzed for the T-beam bridges with five girders, and some conclusions were derived based on this type of bridges. In practice, the bridge type and condition vary between different bridges. Therefore, the effects of a few important factors, including the superstructure configuration, number of girders, type of girder connections, and support conditions, on the optimal transverse truck position were investigated in this section.

Effect of number of girders

In order to investigate the effect of number of girders on the optimal transverse position of overweight trucks, different numbers of girders were adopted for different bridge types. For the T-beam bridges, four different numbers of girders, that is, 4, 5, 6, and 7, were studied. The cross sections of the other three T-beam bridges and the allowable ranges for the transverse truck position are shown in Figure 8.

Figure 9 shows the relative girder bending stress plotted against the transverse truck position. The optimal transverse truck position is also illustrated. Together with the results in Figure 6 for the bridge with five T-girders, it can be concluded that for the T-beam bridges with odd number of girders, the optimal transverse position for overweight trucks is the middle between the center girder and its adjacent girder; for the T-beam bridges with even number of girders, the optimal transverse position for overweight trucks is the centerline of the bridge, which actually coincides with the middle of the two center girders. It can be also observed that the relative bending stress increases dramatically when the truck moves toward the edge of the bridges, indicating again that the edge of the bridge deck is an unfavorable truck loading position.

Effect of type of connections between girders

The concrete joints between girders are subjected to the combined action of traffic loads and environmental attack, and they deteriorate with time. Therefore, the connections between the adjacent girders are somewhere between ideal rigid connection and ideal hinge connection. In order to take this into account, in addition to rigid girder connections, hinged girder connections were also investigated in this study.

The analysis results for the 20-m T-beam bridge with five girders that are hinge-connected are used for illustration and are plotted in Figure 10. It is observed that the relative girder bending stress has larger fluctuation than the bridge with rigid girder connections. Similar to the bridge with rigid girder connections, the relative girder bending stress reaches the minimum when the vehicle is placed in the middle of two adjacent interior girders.

In addition, sudden change occurred when one wheel of the vehicle moved across the hinge connections, which correspond to positions A, B, and C in Figure 10. This can be explained using Figure 11, in which point B in Figure 10 was used for illustration. As the wheel moved over the hinge joint between Girder 3 and Girder 4 (the center of the vehicle was at point B at this moment), from left to right, there was a sudden increase in the vehicle load carried by Girder 4, leading to the sudden increase in the relative girder bending stress as shown in Figure 10. As the wheels moved further to the right, both wheels were carried directly by Girder 4 until the moment when the right wheel moved over the hinge joint between Girder 4 and Girder 5 (the center of the vehicle was at point C at this moment). Once the right wheel moved across this joint, the load carried by Girder 4 experienced a sudden drop, leading to a sudden decrease in the relative girder bending stress as shown by point C in Figure 10.

Effect of type of girders

Analysis was also performed on the box-girder bridges and voided-slab-beam bridges, and the influence of

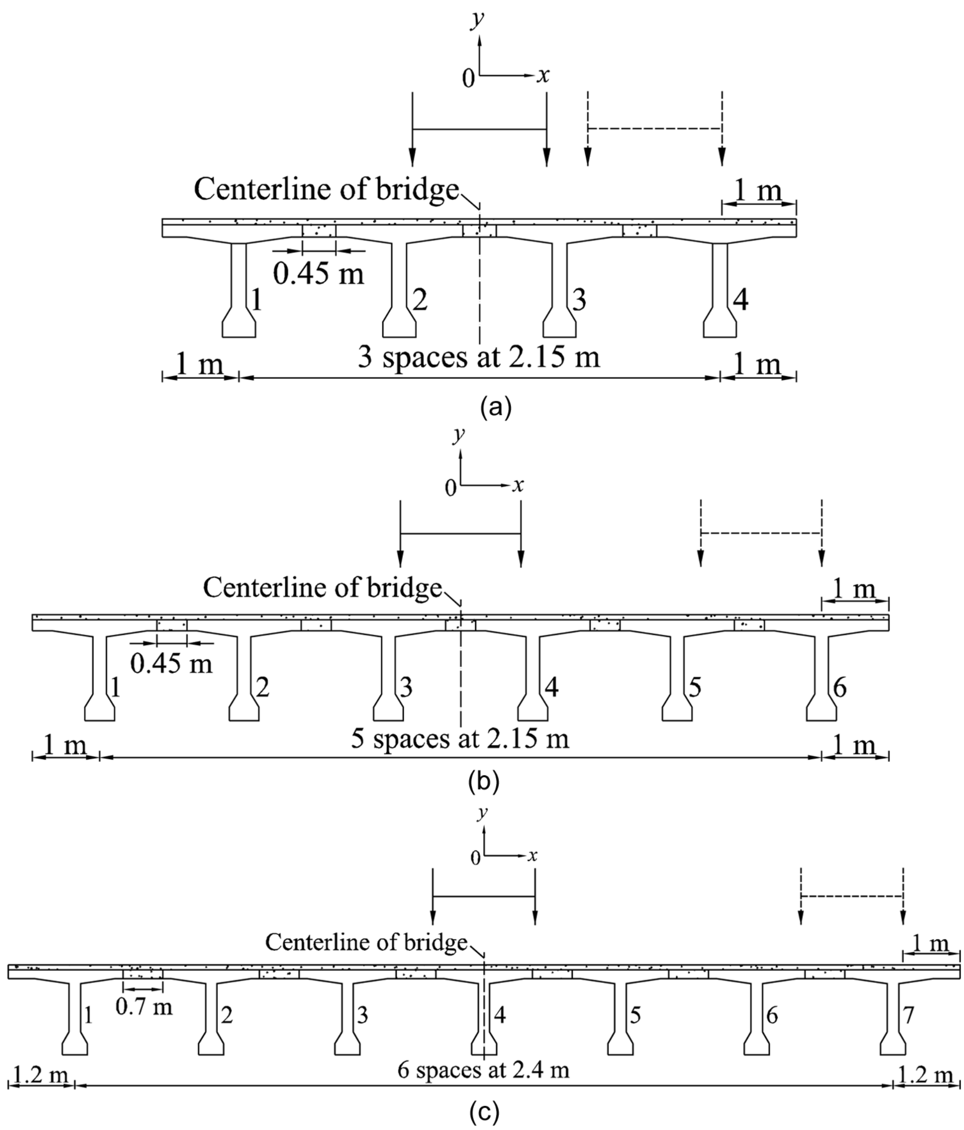


Figure 8. Typical cross sections of the T-beam bridges and allowable ranges for the transverse truck positions: (a) T-beam bridge with four girders, (b) T-beam bridge with six girders, and (c) T-beam bridge with seven girders.

girder type on the optimal transverse position of overweight trucks was also investigated. The span lengths of the box-girder bridges and voided-slab-girder bridges were both set to 20 m. The obtained relative bending stresses for the bridges with different girder types and different types of girder connection are shown in Figures 12 and 13, respectively.

As can be seen from Figure 12, for the box-beam bridges with rigid girder connections, the minimum relative bending stress was obtained when the overweight vehicle was placed between the center girder and the adjacent exterior girder, but slightly to the side of the center girder. At that specific position, the stress on Girder 2 decreased to a level that equaled the stress on Girder 3, which was continuously increased as the truck moved to the right. This was also the critical truck position where the maximum bending stress on a single girder reached the minimum value. As the truck moved further to the right, Girder 3 became the critical girder and more load was carried by Girder 3, leading to an increase in the relative bending stress. However, for the box-beam bridges with hinged girder connections, the relative bending stress reached the minimum when one truck wheel moved just across the hinge connection. The reason was that as the right wheel moved across the hinge joint between Girder 2 and Girder 3, there was a sudden reduction of the vehicle load carried by Girder 2 which was the critical girder, leading to a sudden reduction of the relative girder bending stress.

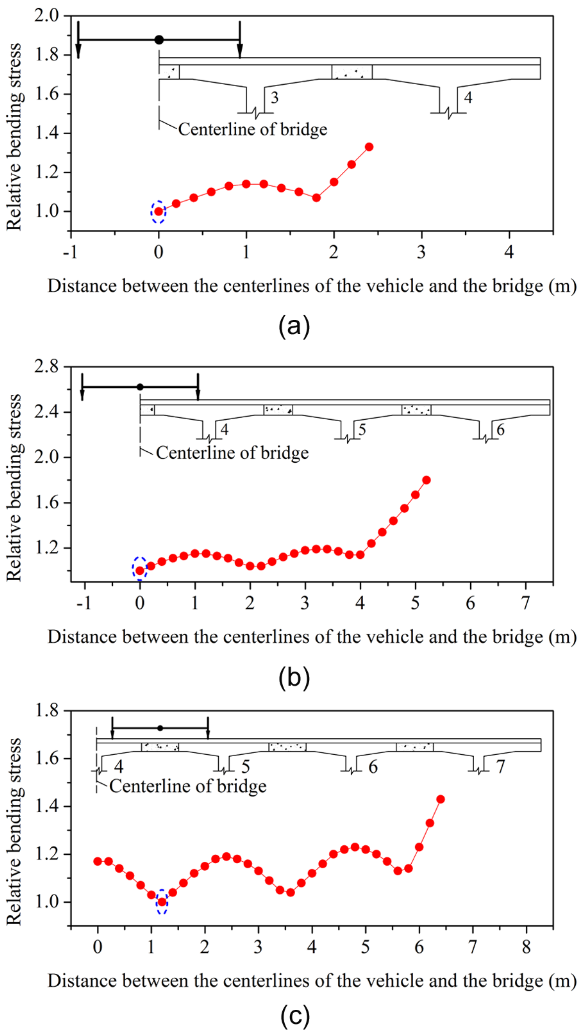


Figure 9. Relative girder bending stress for the T-beam bridges: (a) T-beam bridge with four girders; (b) T-beam bridge with six girders, and (c) T-beam bridge with seven girders.

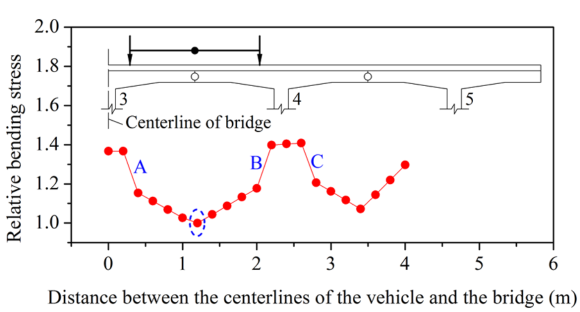


Figure 10. Relative girder bending stress for the 20-m T-beam bridges with hinged girder connections.

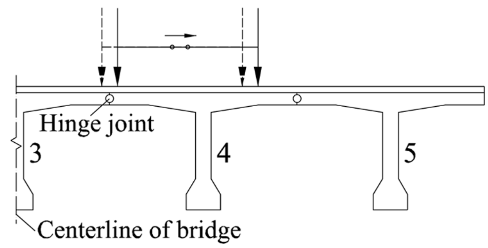


Figure 11. Loading position of the overweight truck on the T-beam bridge with hinged girder connections.

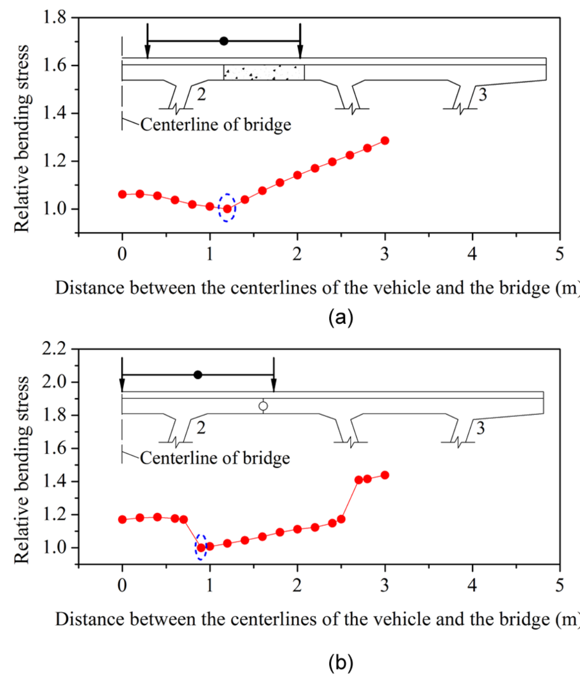


Figure 12. Relative bending stress for box-beam bridges: (a) rigid girder connection and (b) hinged girder connection.

As can be seen from Figure 13(a), for the voided-slab-beam bridge with rigid girder connections, the minimum bending stress was obtained when the truck was positioned at the centerline of the bridge. As the truck moved toward the edge of the bridge deck, the relative bending stress increased continuously. For the voided-slab-beam bridge with hinged girder connections, the minimum relative bending stress occurred when one truck wheel moved across the hinge connection.

For the purpose of comparison, the *RD* in bending stress under the two loading cases defined previously are calculated and summarized in Table 2 for bridges with different types of girders. As can be seen from Table 2, the T-beam bridges have the largest *RD* values, indicating that the maximum bending stress of the T-beam bridges is more sensitive to the transverse truck position. It is probably due to the fact that the stiffness of the T-beam bridges varies significantly in the transverse direction. In contrast, the stiffness of the

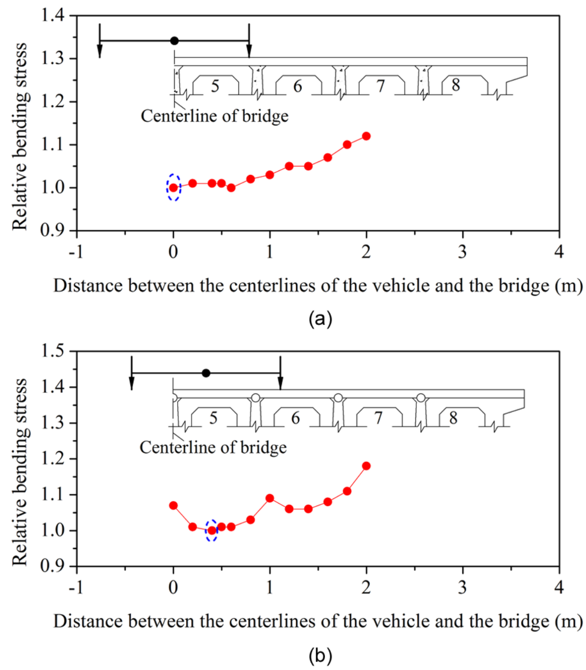


Figure 13. Relative bending stress for the voided-slab-beam bridge: (a) rigid girder connection and (b) hinged girder connection.

Table 2. Relative difference in bending stress for bridges with different type of girders.

Type of girders	*RD* (%)	
	Rigid girder connection	Hinged girder connection
T-beam	15.1	37.2
Box-beam	6.1	17.0
Voided-slab-beam	0	6.5

RD: relative difference.

voided-slab-beam bridges is much more uniform along the transverse direction, leading to smaller *RD* values. For the T-beam bridges, the values of *RD* reached 15.1% and 37.2% for rigid girder connections and hinged girder connections, respectively.

Effect of boundary conditions

All the bridges investigated in the previous sections were simply supported girder bridges. However, the boundary conditions for in-service bridges were influenced by many factors such as the corrosion of bearing and may gradually change with time. Researchers found that the boundary conditions can have a considerable effect on the behavior of bridges (Bakht and Jaeger, 1988; Eom and Nowak, 2001). Studies (Eom and Nowak, 2001; Harris, 2010) have also shown that the actual boundary conditions for simply supported bridges are within the range between the hinge–hinge support and the simple support.

To investigate whether the change of boundary condition has a significant effect on the optimal transverse position of moving trucks on highway bridges, another scenario within which the bridge is hinge-supported at both ends was investigated in this study. The 20-m T-beam bridges with five girders were used again for the purpose of illustration. Similar to the simply supported T-beam bridges, the optimal transverse truck position was found to be in the middle of two adjacent interior girders. Table 3 gives the results of the *RD* in bending stress between the two loading cases defined previously. It can be observed that the *RD*s for the bridges hinge-supported at both ends are larger than those of the simply supported bridges. When the girders are hinge-connected and are hinge-supported on both ends, the value of *RD* is as high as 53.6%.

Table 3. Relative difference in bending stress for bridges with different support conditions.

Support conditions	*RD* (%)	
	Rigid girder connection	Hinged girder connection
Simply supported	15.1	37.2
Hinge-supported on both ends	21.8	53.6

RD: relative difference.

It was reported in Eom and Nowak's (2001) study that the vehicle load distribution on girders is more uniform when the support condition is ideally simply supported than that in the hinge–hinge supported condition. The authors' previous study (Yan et al., 2017) also showed that the boundary condition can greatly affect the live load distribution factor and that the mean values and coefficients of variation of the load distribution factors of the bridges hinge-supported on both ends are larger than those of the simply supported bridges. This explains why large variation in the bending stress was obtained using two hinged supports as compared to the case of using one hinged support and one roller support.

Conclusion

This article investigated the optimal transverse position for overweight trucks to cross simply supported multi-girder bridges. The optimal transverse truck position was defined as the loading position where the maximum bridge bending stress of the girders is minimized.

Finite element analysis was performed for a group of prefabricated concrete bridges under the action of overweight trucks. The effects of superstructure configuration, length of bridge spans, number of girders, type of girder connection, and support conditions were all investigated. Based on the results of this study the following conclusions can be drawn:

1. The transverse loading position of overweight trucks has a significant impact on the responses of multi-girder bridges. For example, for the 20-m simply supported T-beam bridges with five girders, the maximum bending stress at the midspan of the girders when the overweight vehicle moves cross the bridge along its centerline is 15.1%–37.2% larger, depending on the girder connection condition, than the maximum bending stress when the overweight vehicle moves following the optimal transverse position. This finding also reveals the fact that the condition of girder connections has a considerable effect on the bridge response under vehicle loading.
2. The cross influence of the support condition and girder connection condition on the bridge responses is significant. For the 20-m T-beam bridges with five girders, when the girders are rigidly connected and are simply supported on both ends, the maximum bending stress at the midspan of the girders due to the overweight vehicle crossing along the bridge centerline is 15.1% larger than that due to the overweight vehicle moving along the optimal transverse position. However, this difference increases to as high as 53.6% when the girders are hinge-connected and are hinge-supported on both ends.
3. For the T-beam bridges, the optimal transverse position for overweight trucks to travel across the bridge is the middle between the two interior girders. This position may not necessary be the centerline of the bridge (e.g. for bridges with odd number of girders) as suggested by the MOT in China. Similar results were also observed for the box-beam bridges with rigid girder connections. It should be noted that for the box-beam bridges with only three girders, the optimal transverse position for overweight trucks is slightly shifted to the side of the center girder due to the influence of the exterior girder. While for voided-slab-beam bridges with rigid girder connections, the optimal transverse truck position is consistently the centerline of the bridge.

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References

Adams TM, Malaikrisanachalee S, Blazquez C, et al. (2002) Enterprise-wide data integration and analysis for oversize/overweight permitting. *Journal of Computing in Civil Engineering* 16(1): 11–22.

ANSYS 15.0 (n.d.) *ANSYS 14.5 (Computer Software)*. Canonsburg, PA: ANSYS.

Bakht B and Jaeger L (1988) Bearing restraint in slab-on-girder bridges. *Journal of Structural Engineering* 114(12): 2724–2740.

Chen K (2011) *Finite element analysis and strengthening technology for the transverse connection of prefabricated T-beam bridges*. Master's Thesis, Central South University, Changsha, China (in Chinese).

Ding LN, Xia Y and Deeks AJ (2012) Evaluation of bridge load carrying capacity using updated finite element model and nonlinear analysis. *Advances in Structural Engineering* 15(10): 1739–1750.

Eom J and Nowak A (2001) Live load distribution for steel girder bridges. *Journal of Bridge Engineering* 6(6): 489–497.

Fiorillo G and Ghosn M (2016) Minimizing illegal overweight truck frequencies through strategically planned truck inspection operations. *Journal of Transportation Engineering* 142(9): 04016038.

Fu G and Hag-Elsafi O (2000) Vehicular overloads: load model, bridge safety, and permit checking. *Journal of Bridge Engineering* 5(1): 49–57.

Fu Z, Ji B, Cheng M, et al. (2012) Statistical analysis of the causes of bridge collapse in China. In: *Proceedings of the sixth congress on forensic engineering*, San Francisco, CA, 31 October–3 November, pp. 75–83. San Francisco, CA: American Society of Civil Engineers.

Gheitasi A and Harris D (2015) Overload flexural distribution behavior of composite steel girder bridges. *Journal of Bridge Engineering* 20(5): 04014076.

Ghosn M (2000) Development of truck weight regulations using bridge reliability model. *Journal of Bridge Engineering* 5(4): 293–303.

Ghosn M, Parker N, Fiorillo G, et al. (2015) *Effect of overweight vehicles on NYSDOT infrastructure*. Research Project NYSDOT, Report no. C-08–13. Albany, NY: New York State Department of Transportation.

Harris DK (2010) Assessment of flexural lateral load distribution methodologies for stringer bridges. *Engineering Structures* 32(11): 3443–3451.

Hays CO, Consolazio GR, Hoit MI, et al. (1995) Meteric/SI and PC conversion of BRUFEM and SALOAD system, Report, University of Florida, Gainesville, FL.

Kim YJ, Tanovic R and Wight RG (2013) A parametric study and rating of steel I-girder bridges subjected to military load classification trucks. *Engineering Structures* 56: 709–720

Li Y, Zhang J, Chen Y, et al. (2017) Ultimate flexural capacity of a severely damaged reinforced concrete T-girder bridge. *Journal of Bridge Engineering* 22(5): 05017003.

Ministry of Transport of the People's Republic of China (MOT) (2000) *Regulation of Highway Transportation Management for Overweight Vehicles*. Beijing, China: MOT.

Standardization Administration of the People's Republic of China (SAC) (2004) *Limits of Dimensions, Axle Load and Masses for Road Vehicles*. Beijing, China: SAC.

Vigh A and Kollár L (2006) Approximate analysis of bridges for the routing and permitting procedures of overweight vehicles. *Journal of Bridge Engineering* 11(3): 282–292.

Vigh A and Kollár L (2007) Routing and permitting techniques of overweight vehicles. *Journal of Bridge Engineering* 12(6): 774–784.

Wood SM, Akinci NO, Liu J, et al. (2007) Long-term effects of super heavy-weight vehicles on bridges. Joint Transportation Research Program Final Report, Purdue University, West Lafayette, IN, December.

Xu J (2009) *Study on the whole rigidity of T-beam bridges*. Master's Thesis, Changan University, Xi'an, China (in Chinese).

Yan J, Deng L and He W (2017) Evaluation of existing prestressed concrete bridges considering the randomness of live load distribution factor due to random vehicle loading position. *Advances in Structural Engineering* 20(5): 737–746.

Yin W (2012) *The method research of determining limited load value for overweight vehicles cross bridges based on reliability theory*. Master's Thesis, Guangdong University of Technology, Guangzhou, China (in Chinese).

Yousif Z and Hindi R (2007) AASHTO-LRFD live load distribution for beam-and-slab bridges: limitations and applicability. *Journal of Bridge Engineering* 12(6): 765–773.

Zhang XG (2014) *Study of Highway Bridge Vehicle Loads*. 1st ed. Beijing, China: China Communications Press.

Zhao J and Tabatabai H (2012) Evaluation of a permit vehicle model using weigh-in-motion truck records. *Journal of Bridge Engineering* 17(2): 389–392.

Zong X (2003) *Evaluation and management of bridges subjected to overweight vehicles*. Master's Thesis, Changan University, Xi'an, China (in Chinese).