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A COMPARATIVE STUDY OF THE BENDING MOMENTS ANALYSIS FOR THE CROSS GIRDER IN A TWO-LANE TWO-WAY HIGHWAY BRIDGE UNDER ACTUAL TRAFFIC AXLE WEIGHTS AND THE EGYPTIAN DESIGN LOAD STANDARDS

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ABSTRACT

In many countries, including Egypt (ECP 201-2012), bridges are designed based on international codes such as AASHTO and EN 1991-2:2003 specifications. The Egyptian code for vehicle loads on bridges is based on the Eurocode (EN 1991-2:2003). However, local trucks often exceed these specified design truckloads, increasing the probability of damage, shortened service life, and potential bridge failure. This study evaluates the bending moments for the cross girder of a two-lane, two-way highway bridge under various loading conditions. Site surveillance collected data on actual traffic parameters, including axle weights, vehicle weights, headway distances, vehicle types, axle spacing, and vehicle speeds. The study utilized the Monte Carlo Simulation technique, a MATLAB algorithm, and the finite element method via SAP2000 to model different loading scenarios and the probability of lane occupation for span lengths ranging from 20 meters to 80 meters. The analysis of gross vehicle weight data found that 42.7% of the heavy trucks examined exceeded the GARBLT weight limitations. Furthermore, the highest axle overload factor observed was 2.7. These findings highlight the significant risk that overloaded trucks pose to bridge strength and safety. The resulting bending moments were then compared with the Egyptian design load standards. The findings of this study will contribute to developing a more accurate and reliable method for evaluating bridge loads, significantly enhancing the safety and reliability of highway bridges in Egypt.

KEYWORDS: Monte Carlo simulation, Overloaded trucks, Time headway, Bridge Loading.

دراسة مقارنة لتحليل عزوم الانحناء للكمرات العرضية لكوبرى سريع حارتين في اتجاهين تحت الأوزان الفعلية لاحمال المرور ومعايير الأحمال التصميمية المصرية

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الملخص

فى العديد من البلدان بما في ذلك مصر يتم تصميم الكبارى بناء على الاكواد العالمية مثل الكود الامريكى (الاشتو - الكود الاوروبى) حيث ان الكود المصرى لاحمال المركبات على الكبارى يعتمد على الكود الاوروبى غالبا ما تتحاوز الشاحنات هذه الاحمال مما يزيد من احتمالية حدوث أضرار لجسم الكوبرى وتقليل عمر خدمة الكبارى ولهذا أجريت هذه الدراسة لتقييم عزوم الإنحناء للكمرات العرضية لكوبرى سريع حارتين في إتجاهين تحت ظروف تحميل مختلفة بإستخدام عمل مسح ميدانى وتجميع بيانات عن الأحمال الفعلية الخاصة بالشاحنات، أبعاد المركبات الموجودة فى مصر، والمسافات البينية بين المركبات، ونوع المركبات، والمسافة بين المحاور، وسرعة المركبات. استخدمت الدراسة تقنية محاكاة مونتي كارلو، MATLAB وطريقة العناصر المحددة باستخدام برنامج (SAP2000) لنمذجة حالات مختلفة من التحميل على الكوبرى المدروس، بأطوال مختلفة تتراوح بين (20 م إلى 80 م)، اظهر تحليل بيانات اوزان المركبات ان 42.7 % من هذه المركبات تتجاوز الأحمال المسموح بها من الهيئة العامة للطرق والكبارى والنقل البرى تمت مقارنة هذه العزوم مع العزوم الناتجة عن الأحمال التصميمة المنصوص عليها فى الكود المصرى لأحمال الكبارى. بناءً على نتائج التحليل الثلاثى الابعاد ، يمكن استنتاج أن الحمولة العشوائية لحركة المرور التي تم إنشاؤها باستخدام البيانات الفعلية المقاسة تؤدي إلى عزوم انحناء أقل من الحمولة التصميمية القياسية سواء كان الكوبرى المدروس يرتكز ارتكازا بسيطا او كوبرى مكون من باكيتين. ستسهم نتائج هذه الدراسة في تطوير طريقة تقييم الكبارى بدقة وموثوقة أكثر، وتعزيز سلامة وأمان الكبارى في مصر.

الكلمات المفتاحية : محاكاة مونتي كارلو، الحمولات الزائدة للشاحنات، الفاصل الزمني، احمال الكبارى

1. Introduction

The safety, economy, and durability of a highway bridge are closely tied to operational vehicle loads, which must be adjusted for traffic flow, traffic volume, transportation conditions, and future development patterns. However, with rapid expansion and the national economy, as well as the requirement for heavy-load transportation, heavy vehicles, and overload vehicles are frequently seen on the highway, potentially causing the deterioration of highway bridges. The traffic load models outlined in regulatory codes are specially indicated to be conservative, ensuring their applicability across various bridge types and loading scenarios. In many countries, the same assessment standards are used consistently for bridge managing heavy traffic with overloaded trucks as well as moderate traffic with lighter trucks. Analyzing statistics of traffic weights and volumes for a specific bridge provides a clearer understanding of the actual loading condition on the evaluated bridge, potentially leading to cost savings [1], [2].

Handling the effects of traffic loads is challenging due to their inherent randomness, which is influenced by factors such as the types of vehicles, number of axles, weight, weight distribution, and positioning of vehicles on the bridge. This high level of randomness makes it difficult for standard design load organizations, leading to the use of conservative simplifications to ensure safety[3]. In many countries, including Egypt (ECP 201-2012), bridges are designed based on international codes such as AASHTO and EN 1991-2:2003 specifications. The Egyptian code for vehicle loads on bridges is based on the Eurocode (EN 1991-2:2003). However, local trucks often exceed these specified design truckloads, increasing the probability of damage, shortened service life, and potential bridge failure.

Research on the vehicle load has received a lot of attention due to its randomness, time-varying, and regional nature. Baliey et al. [4] defined the distribution of various vehicle types using measured vehicle data and identified 14 typical vehicle categories that contributed 99% of traffic flow for probability distribution analysis. Fu and Osman [5] provided a technique for creating vehicle load models that incorporate overloaded scenarios. They presented a formula for estimating resistance in bridge overload assessments, which was utilized to analyze the reliability of highway bridges.

Getachew and OBrien [6] found that the model used to describe the tail for Gross Vehicle Weight (GVW) distributions significantly affects the predicted typical load effects. Nowak et al. [7] have suggested probabilistic models for vehicle loads and conducted thorough investigations into the method for estimating model parameters, based on the conformity of vehicle load to the multimodal distribution. Kozikowsk [8] collected vehicle data and applied the extrapolation method to develop a specific program to calculate the maximum value of the vehicle load effect. The analysis of multiple vehicles' impact on the bridge was carried out and the existing design specification was evaluated. Obrien et al [9] used the data collected by the weigh-in-motion (WIM) as samples to simulate traffic flow by the Monte Carlo technique and developed traffic load models with various probabilistic methods.

The Misr National Transport Study (MiNTS) reveals that 98.6% of its domestic cargo relies on this road network [10], clearly demonstrating the significant role the road network plays in the national economy and daily activities of the people.

Vehicle weight specifies the design requirements for roadway infrastructure like pavements and bridges. Traditional weigh stations are frequently used to weigh vehicles and issue fines or penalties for violating weight limitations. They, however, spend quite some time weighing each vehicle. Furthermore, the costs of system installation and maintenance are high.

The expansion in industrial operations and rising fuel costs, along with the increase in road freight transportation, have led to a trend of drivers exceeding legal weight limits by using heavier trucks to make road transport more cost-effective.

Overloading is a major concern in Egypt's transportation sector, causing roads to deteriorate prematurely and obstructing the sustainable development of the highway network. Overloading reduces the economic benefits of road construction and raises maintenance costs. The principal negative effects of overloading include:

1- Excessive axle loads and high tire pressures cause early and rapid deterioration of both existing and new roads and bridges, resulting in cracking, rutting, and potholes.
2- Excessive deterioration accelerates and increases road maintenance expenses.
3- Trucks being off-road for repairs due to overloading result in lost transport time and revenue for the owner, who also bears the repair costs.
4- Overloading fines affect the earnings of the transportation sector. The additional axle load increases the whole weight of the truck, contributing to a longer stopping distance when braking, which could lead to major accidents .

Histograms of traffic data collected such as GVW are generally fitted with suitable probability density functions, which are subsequently used in simulations. The aim of applying fitted distributions in simulations is to represent the current pattern in the data, while also adjusting for other possible vehicle statistics that were not collected from traffic records during the data collection period. The right-hand tails of GVW histograms typically contain few data points. Parametric probability density functions derived by fitting to the complete histograms of GVW can provide an inaccurate representation of the histogram tails. The right-hand tail of the histogram is especially significant because it describes the heaviest vehicles and describes their likelihood of occurrence [1].

Nowak and Szerszen [11] summarized and developed a method for calculating the maximum bending moment and shear force for diferent periods by investigating the measured vehicle load data and extrapolating the maximum load efect from 1 day to 75 years.

Zhao and Tabatabai [12] investigated the bending moment and shear effects on two- and three-span continuous beams using comprehensive truck data obtained by weigh-in-motion (WIM) systems. They suggested adding a 5-axle single-unit truck model to Wisconsin's existing standard vehicle categories.

Lang Liu and Lexian Zhang [13] stated that according to 20 loading cases for a simply supported pre-stressed concrete T-beam model with three loading levels, considering one-lane, two-lane, and three-lane loads, the results show that the bending moment induced by heavy trucks moving on multiple lanes was 1.6 times the value of the standard truck model in the Chinese specification.

Iatsko and Nowak [14] used weigh-in-mothion (WIM) data from 44 locations around USAto updatdted the statistical paramerters of live load and verify the validity of the design live load provisions in AASHTO LRFD.the analysis showed that there was 15 % -20% increase in live load in comparison to Ontario data, and recommended to make a change to the current design live by increasing the tandem to 130 KN per axle in additionto lane load of 0.64 kips/ft.

2. Methodlogy

This research was organized according to the research methodology flowchart presented in **Fig. 1.** Data obtained from Cairo - Alexandria agricultural road reveal that the average truck percentage equals 12.71%.

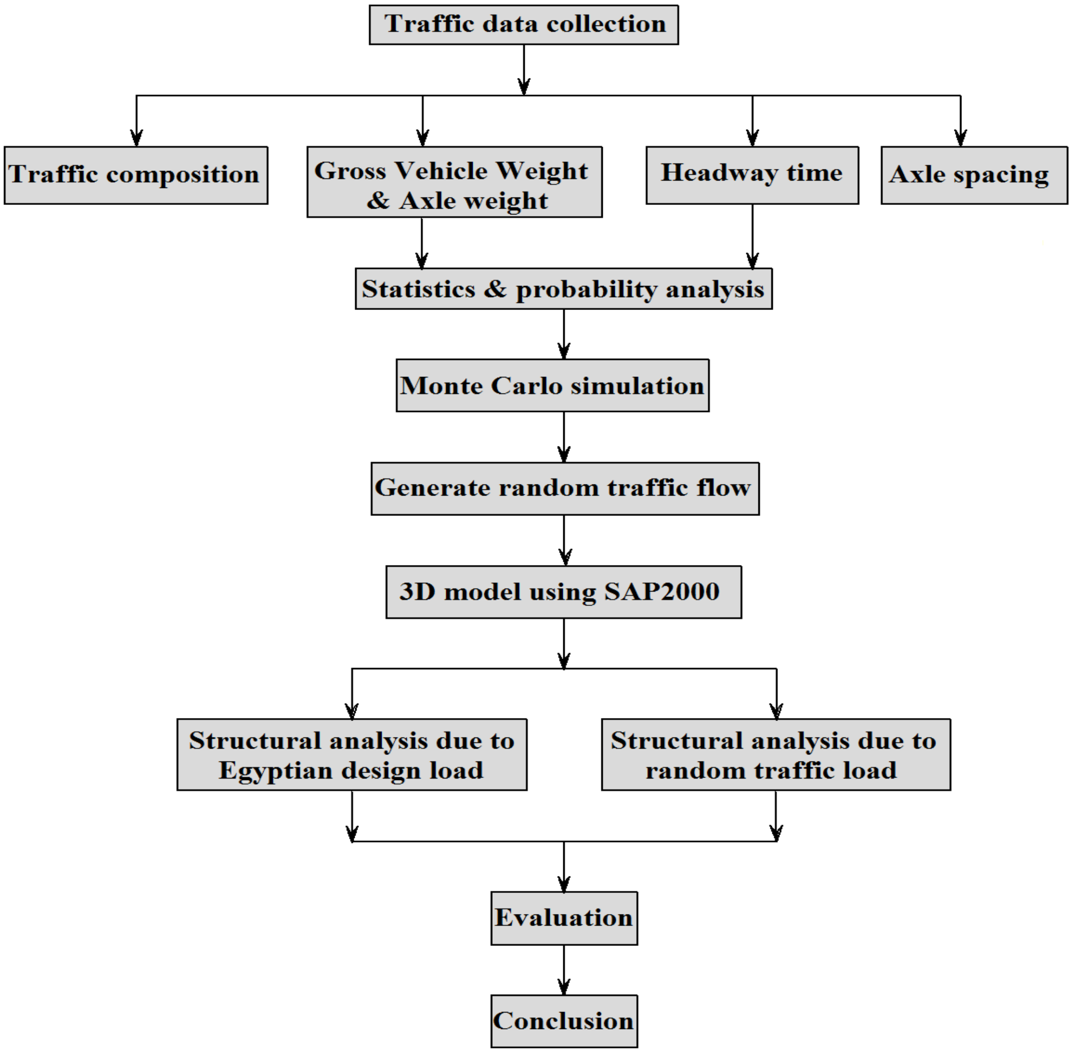
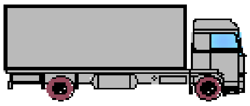
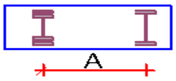
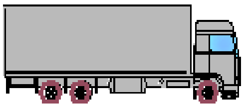
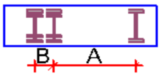
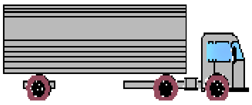
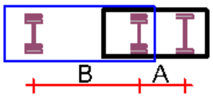
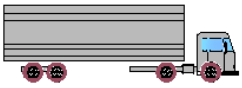
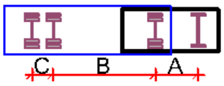
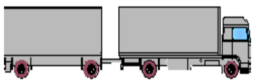
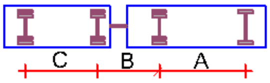
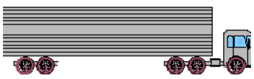
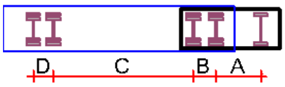
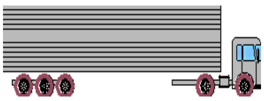
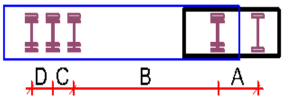
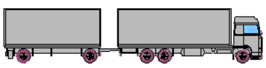
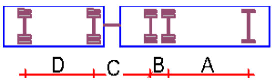
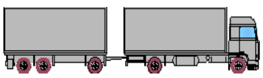
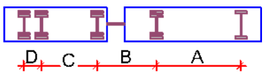
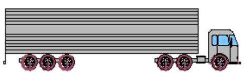
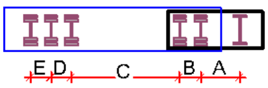


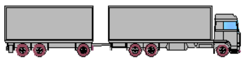
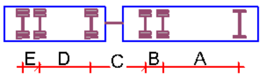
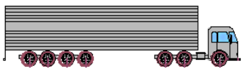
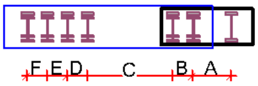
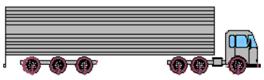
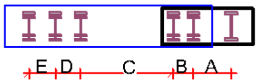
Fig. 1. Research methodology flowchart

2.1. Gross Vehicle Weight & Axle Weight

(GARBLT) has categorized trucks into 9 groups based on the number of axles, regardless of the specific vehicle type. To differentiate between vehicle types with the same number of axles, the truck groups needed to be further subdivided. When taking into account the vehicle type, the total number of truck groups amounts to 13, as indicated in Table 1, which displays the average dimensions for heavy trucks collected by the authors and the legal axle loads.

Table 1. Maximum permissible load & average dimension for different types of trucks

Truck type	Axle configuration	Wheel arrangement	Wheelbase (m)	Axleload(ton)	Limit GVW(ton)
1			A = 4.20	13 7	20
2			A = 3.85 B = 1.30	20 7	27
3			A =4.50 B = 5.25	13 13 7	33
4			A = 3.90 B = 4.00 C = 1.30	20 13 7	40
5			A = 4.50 B = 5.35 C = 4.60	13 13 13 7	46
6			A = 3.55 B = 1.30 C = 6.33 D = 1.30	20 20 7	47
7			A = 4.50 B = 5.70 C = 1.30 D = 1.30	30 13 7	50
8			A = 4.50 B = 1.30 C = 5.35 D = 4.60	13 13 20 7	53
9			A = 4.50 B = 5.35 C = 4.60 D = 1.30	20 13 13 7	53
10			A = 3.55 B = 5.70 C = 6.33 D = 1.30 E = 1.30	30 20 7	57

11			A = 4.50 B = 1.30 C = 5.35 D = 4.60 E = 1.30	20 13 20 7	60
12			A = 4.50 B = 1.30 C = 5.85 D = 1.30 E = 1.30 F = 1.30	36 20 7	63
13			A = 4.50 B = 1.30 C = 5.85 D = 1.65 E = 1.65	13 13 13 20 7	66

Egypt has yet to implement a new weigh-in-motion system and still relies on traditional methods for measuring truck weights. Due to the absence of current weigh-in-motion (WIM) traffic measurements on Egyptian highways, data on truck weights was gathered from platform scales at logging industrial facilities and the weighing station at Alexandria port.

The total weight of more than 4700 trucks was measured and documented across various truck types, with no available data for trucks categorized as types 3, 9, 12, and 13.
Fig. 2 illustrates the measured distributions of Gross Vehicle Weight (GVW) of trucks types recorded. Through the analysis of trucks weight data , the results showed that 42.9% of the collected dats exceed the permitted GVW limits.

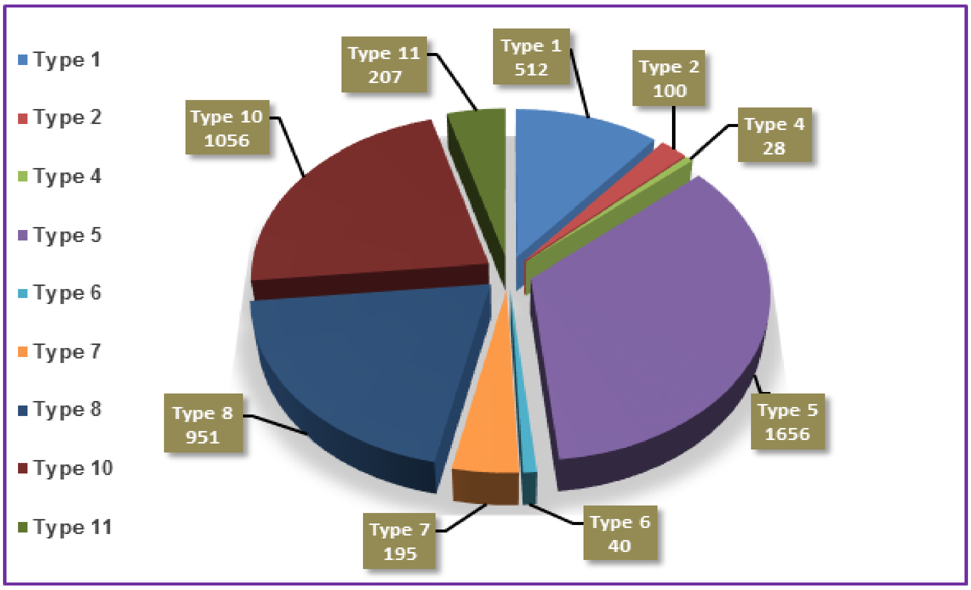


Fig. 2. The measured distribution of gross vehicle weight of trucks types
Source : Author

2.2. Axle spacing

The average dimensions for heavy trucks collected by the authors as shown in Table 1.

2.3. Time headway

The time headway (i.e. headway) can be defined as the time between two successive vehicles when they pass a single point on a roadway [14]The headway time data were collected from two locations from two-lane, two-way (Zifta- Banha), and (El-Santa- Tanta). All the sections are straight, and each lane is 3.6 meters wide. For simplicity, vehicles traveling across the work zone are grouped into just two categories, cars and trucks.

A video camera was used to record traffic during non-peak and peak periods to identify the loading conditions and the types of vehicles in each lane. After recording the data, the time headway between two successive vehicles was calculated by estimating the time difference between the passing of leading and following vehicles over the test point of each lane. The frequencies of the time headways and their corresponding percentages for each time headway interval are shown in Fig. 3. Table 2 presents the 8 loading scenarios according to the traffic pattern and number of lanes. Data were collected for each load case. Four common probability distributions were considered, namely lognormal, gamma, exponential, and Weibull. The optimal parameters for each distribution model were determined to get the closest match between the distribution function and the sample data. Figs. 4 and 5 show the best-fitted distribution for the loading conditions and the headway, respectively.

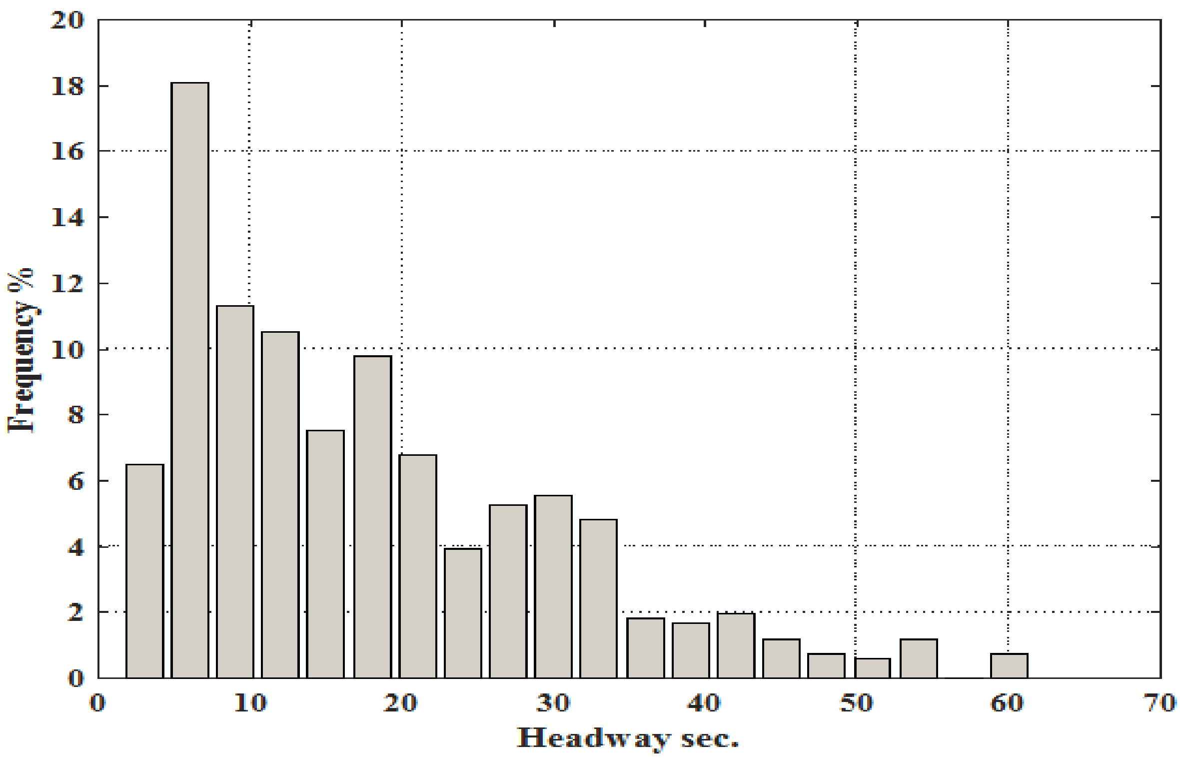


Fig. 3. Headway time frequency
Source : Author

Table 2. Expected case of loading acoording to traffic pattern of each lane

Traffic pattern of each lane		Lane 1		
		Empty	Pc	Truck
Lane 2	Empty	Case 1	Case 2	Case 3
	Pc	Case 4	Case 5	Case 6
	Truck	Case 7	Case 8	Case 9

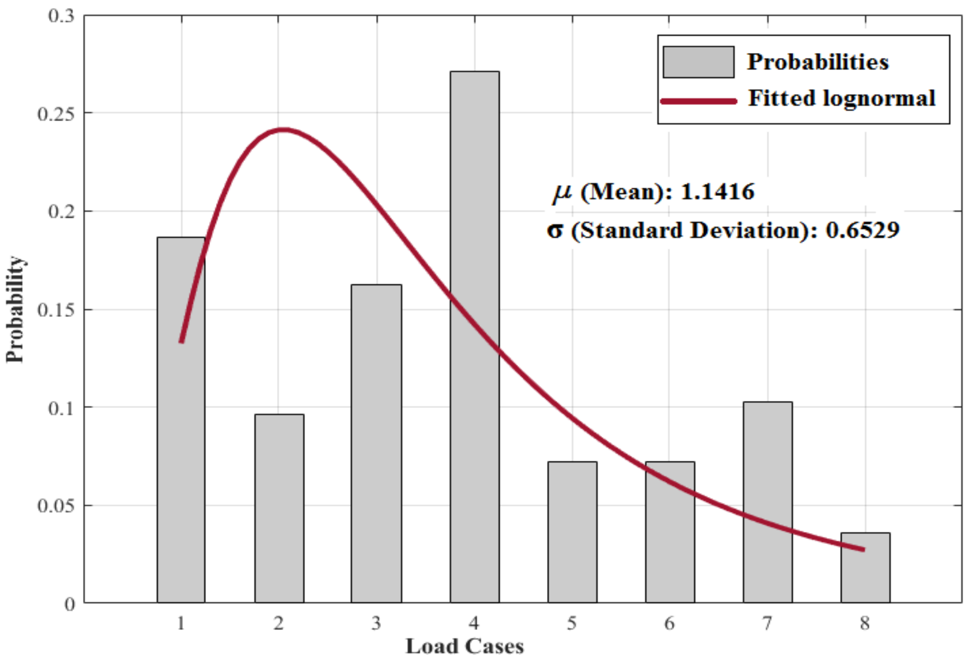


Fig. 4. Best fitting probability distribution for case of loading

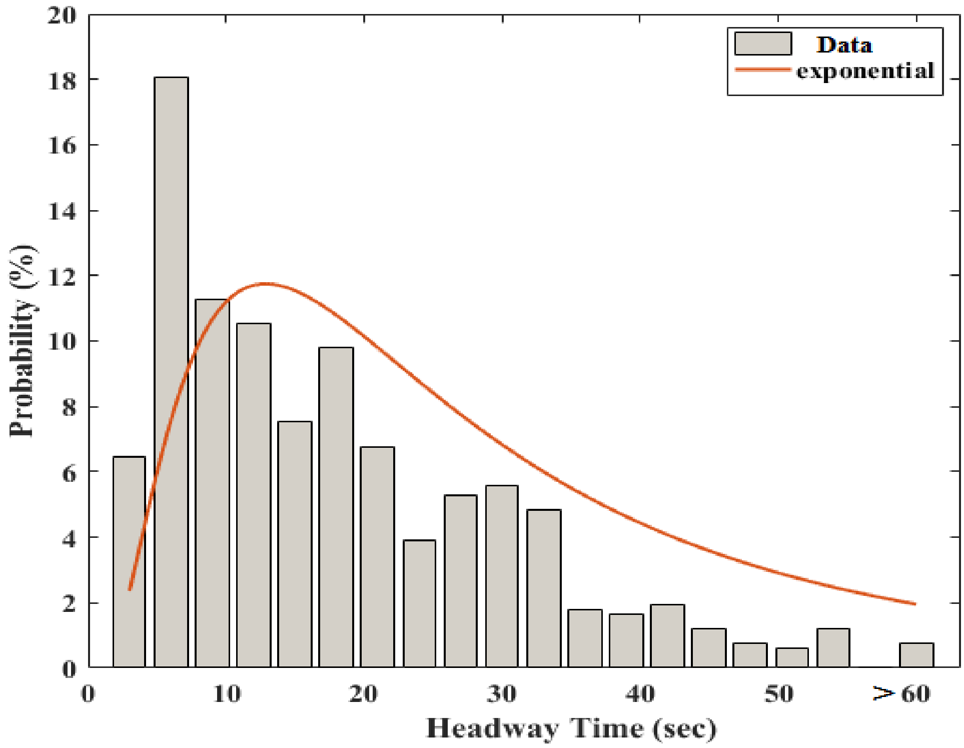


Fig. 5. Best fitting probability distribution for headway time

2.4. Statistics & probability analysis

In order to simulate traffic, the probability density functions (PDFs) of typical traffic parameters, such as gross vehicle weight (GVW), axle weight, and vehicle spacing, were fitted to each of the 11 truck class GVW histograms. The best model was chosen based on Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC), which are statistics associated with each corresponding fitted model in terms of log-likelihood. The most accurate model has the smallest AIC [16]. Traditional probability distributions with a single peak cannot appropriately describe the actual vehicle load for truck types 1, 5, 7, and 10, so a trimodal distribution, with three segments, was used. **Table 3** summrizes the parameters on the distribution fitted to GVW histograms. MATLAB was utilized to fit the PDFs and draw fitting curves.

Table 3. The probability distribution and distribution parameters with different truck type

Truck Type	Distribution	Parameters		
		Shape	Location	Scale
1 - A	Extreme Value	-	9.4447	0.6225
1 – B	Extreme Value	-	18.0733	2.059
1 – C	Generalized Extreme Value	0.14	1.489	23.6299
2	Generalized Extreme Value	0.2191	2.931	17.1401
4	Gamma	11.8919	-	2.9927
5 – A	Generalized Extreme Value	0.0833	0.8737	19.2356
5 – B	Generalized Extreme Value	- 0.03913	6.023	37.7059
5 – C	Generalized Extreme Value	0.0246	4.4975	55.9844
6	Gamma	7.0955	-	6.0038
7 – A	Extreme Value	-	23.2377	1.7339
7 – B	Weibull	40.1081	-	10.5388
7 – C	Loglogestic	4.1773	-	0.0741
8 – A	Generalized Extreme Value	- 0.0413	3.4264	22.6721
8 – B	Generalized Extreme Value	- 0.3141	8.817	47.2751
8 – C	Generalized Extreme Value	- 0.7638	7.695	79.9733
10 – A	Generalized Extreme Value	0.1367	2.5845	24.5145
10 – B	Generalized Extreme Value	0.4512	3.7247	40.4447
10 – C	Generalized Extreme Value	0.3305	4.192	66.7502
11	Lognormal	-	3.7774	0.4484

2.5. Monte Carlo simulation

Monte Carlo simulation is an effective technique for estimating the maximum bridge loading expected to occur over its lifetime. The purpose of this technique is to simulate traffic that matches the load effect distribution of the collected data, while also including trucks that are heavier and have more axles than those observed in the measured data [17].

2.6. Generation random traffic flow

As mentioned earlier, the characteristics of the vehicles were represented as random variables following various probability models. These variables can have a variety of effects on how the bridge. The study utilized the Monte Carlo method to simulate how the bridge would respond to random traffic flow. To perform this simulation and generate random traffic flow, a MATLAB code was developed[18].

2.7. 3D model using SAP2000

To analyze the effect of live load under random traffic flow, a three-dimensional (3D) finite element model was created using the finite element application SAP2000 V.14. This model was used to perform a comparative analysis of the cross girder for a two-lane, two-way highway under random traffic load and the Egyptian design load.

According to ECP-201:2012[19], three different load models are specified: Load Model 1 (LM1), Load Model 2 (LM2), and Load Model 3 (LM3). LM1 is designated for designing various components of the substructure and superstructure, excluding bridge deck slabs. LM2 is exclusively utilized for designing bridge deck slabs, while LM3 is applicable only to pedestrian bridges. LM1 consists of a combination of concentrated loads and uniformly distributed loads as shown in Fig. 6. Fig. 7 and Table 4 show the cross section and the specifications for the bridges considered in this study.

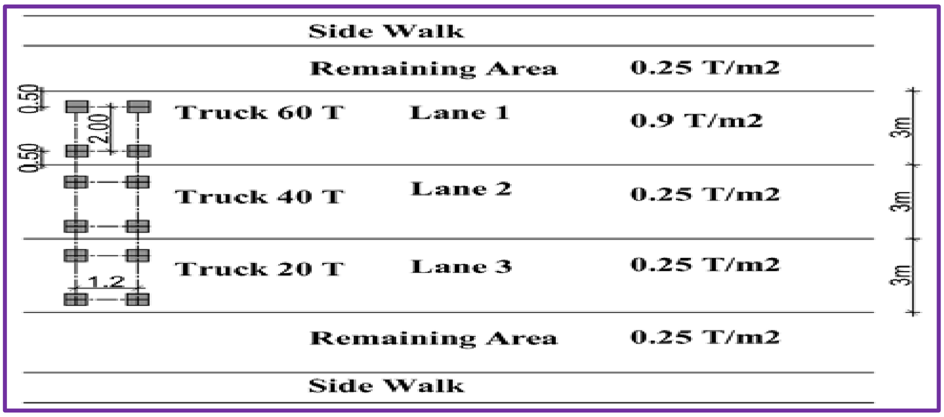


Fig. 6. Load Model 1 of vehicular live load according to ECP-201:2012

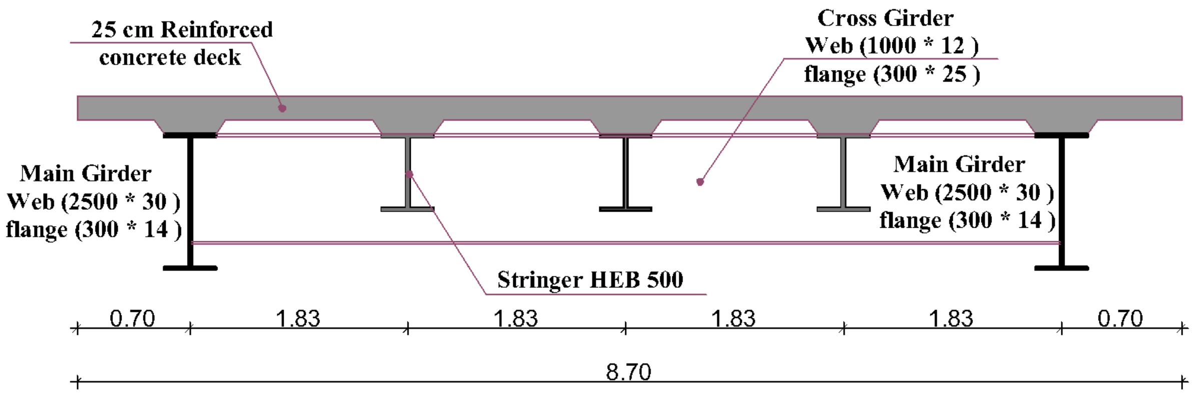


Fig. 7. Cross section considered in this study

Table 4 The characteristics of the bridge were used to generate model cases

No	Span	No. of lanes	Span length (m)	No. of Girders	No. of Cross Girders	Girder Spacings (m)	Total Width (m)	Overhang length (m)	Total Wiwth (m)
1	Simple	2	20	5	5	1.83	7.3	0.7	8.7
2	Simple	2	30	5	7	1.83	7.3	0.7	8.7
3	Simple	2	40	5	9	1.83	7.3	0.7	8.7
4	Continuous	2	20	5	5	1.83	7.3	0.7	8.7
5	Continuous	2	30	5	7	1.83	7.3	0.7	8.7
6	Continuous	2	40	5	9	1.83	7.3	0.7	8.7

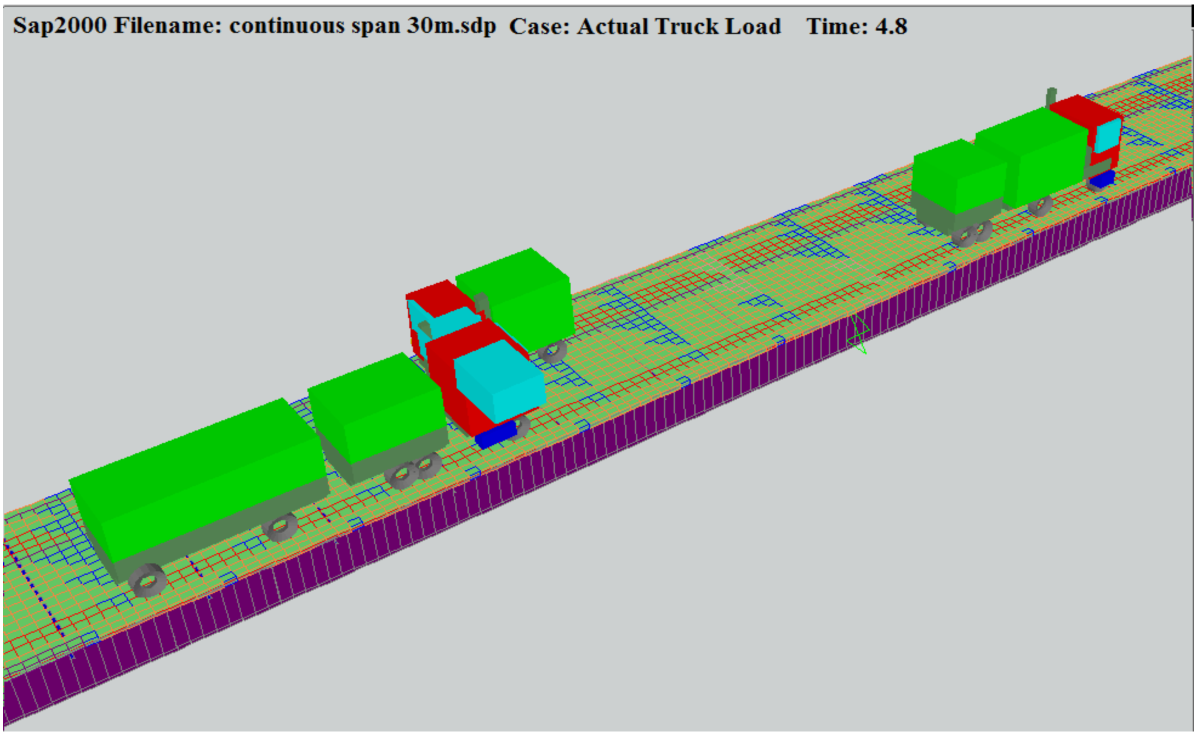


Fig. 7. SAP2000 modeling random traffic load

After assigning vehicle loads to the model, 18 bridge models were generated for the study, each subjected to traffic load (with 3 sets of load generated for each case). All 18 test bridges were developed using Finite Element Analysis (FEA), and their results were compared to the standard design load specified in the Egyptian code. The maximum bending moment for the cross girder resulting from the generated traffic load and the standard design load was determined and presented in Table 5.

Based on the data in Table 5, it is evident that the traffic load obtained from the measured data produces a bending moment for both simply supported beams and continuous beams that is lower than the standard. Specifically, the bending moment ratio ranges between 70.23% and 90.99% for simply supported beams, and between 81.07% and 99.02% for continuous beams.

Table 5 maximum bending moment

Span (m)	Simple		Ratio	Continuous		Ratio
	Bending moment due to generated traffic load (t.m)	Bending moment due to generated traffic load (t.m)		Bending moment due to generated traffic load (t.m)	Bending moment due to generated traffic load (t.m)	
20	56.23	80.06	70.23%	63.36	78.15	81.07%
30	71.67	79.62	90.02%	71.07	79.79	89.07%
40	72.37	79.5	90.99%	79.74	80.53	99.02%

2.8. Conclusion and Recommendation

Based on the research results, the following conclusion can be drawn:

1- According to the data gathered on the time headway between vehicles, it was determined that the most suitable probability distribution is the exponential distribution.

2- The analysis of gross vehicle weight data found that 42.7% of the heavy trucks examined exceeded the GARBLT weight limitations. Furthermore, the highest axle overload factor observed was 2.7. These findings highlight the significant risk that overloaded trucks pose to bridge strength and safety.

3- The findings from the 3D analysis of the cross girder indicate that the random traffic load generated using the actual measured data results in bending moments that are less than the standard design load across varying spans of the main girder.

4- At a continuous span length of 40 meters, the bending moment ratio approached 100%, indicating a potential risk to the bridge's strength.

5- This conclusion highlights the necessity of additional research and future adjustments to standard design load with longer spans.

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