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Flexure and shear load rating evaluation of composite bridge superstructure under effect of different trucks load types

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ABSTRACT

The purposes of this study were to provide a methodology for comparing between structural members of composite bridge due to flexure and shear load rating. Also it was used to evaluate and determine the load capacity of composite bridge structural members by adopting load rating analysis method through using different types of international trucks. CSI bridge Ver. 20 was used in the analysis process. The results of flexure and shear, load rating shown that the left and right girders carried the higher values of flexure and shear load rating for all types of trucks load. The structural member of bridge which was subjected to higher values of flexure and shear load rating had sufficient live load carrying capacity, more elasticity and stiffness, indicating that the values of static structural parameters such as bending moment, vertical shear force, vertical displacement and axial force were lower than structural member had minimum values of flexure load rating. The results of factored bending moment, vertical shear force, and axial force shown that truck type LM3-3600/240 had the higher values of factored bending moment, vertical shear force, and axial force within exterior girders which were appeared minimum flexure load rating. The minor values of factored bending moment, vertical shear force, and axial force were happened under effect of truck type AML and Hsn-44L because of these trucks had higher flexure and shear load rating. The maximum value of vertical displacement was 29 mm under truck type LM3-3600/240 which had lower flexure load rating.

1. Introduction

A bridge engineering is an important branch in the transportation and civil engineering which is ordinarily used in life of highways and bridges users. Structure of bridges can be provided a main connection between highways, railways, in intersections, two edges of rivers, and between mountains. In general, all forms of bridges structures can be contained on two parts which they known as superstructure and substructure. Typically, the bridge superstructure contains on pavement coarse, reinforced concrete deck (ordinary or prestressed), and different shapes of girders (ordinary or prestressed). The substructure denotes to a foundation of bridges which include abutments, piers, piers cap, and bearings [1–6].

Bridge structure evaluation is ever more significant subject in the determination to deal with the deterioration of bridge structure. In general, there is needing to adopt suitable methods of design and analysis to calculate the real strength of the bridge structure, its service life, and the real load scale. There are two types of live load can be affected the bridge structure which are static and dynamic types. The important factors of load can be applied on the bridges structures are including trucks number and trucks weights. Moments and shear forces are calculated for various spans of bridge because of bridges structure can be affected by loads rather than gross trucks weights. Most references were defined live load as a load that transfers alongside of span length. For safety and cost-effective design of bridges, determination of suitable live load due to trucks weights (traffic Loads) is necessary. The essential combination of loads which is used in the design of bridge includes the combined of dead load (self-weight of structure), live load (Traffic load), Temperature load (thermal load), wind load, and seismic load. The safe traffic load carrying capacity of the bridge can be identified as bridge load rating [7,8]

The assessing of bridges load carrying capacity is an significant procedure, and it is main in informing drivers of any load carrying

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insufficiencies by posting load constraints. Bridges structures are rated at two levels, inventory and operating levels. The load rating is an indication of bridge live load capacity. According to AASHTO Manual for bridge evaluation, inventory rating level can be defined as the passing traffic loads in many lanes which can be provided safely service the bridge for an unknown period of time. The operating rating level can be known as the higher acceptable traffic live load which can be applied on the superstructure of bridge [9,10]

Bridge load rating is a process which is use to evaluate the appropriateness of different structural parts of bridge structure to carry scheduled live loads of trucks. Load ratings are necessary for all new constructed bridge and old bridges which are needed repairing to increase the load carrying capacity of the bridge. Load ratings must complete directly after the completing of bridge design, and rating determinations can be filed individually. The organized load model should agreement all newly designed bridge to have minimum safety under effects of future traffic loads. Load ratings of bridge are known with various stages of reliability and they offer a source for choices on weightiness assignment, overload truck certificates, and structural strengthening or repairing [11,12,13,14].

Load rating of the bridge structure can be completed by using the similar methodology which was used in the design and it is normally done by adopting serious information obtainable on the bridge plans. The information includes span distances and dimensions of the bridge parts, the kind and features of materials which was used to build the bridge, and actual and future traffic loads. These data are used to implement a essential analysis which was used to analyze the forces or stresses produced by different types of loads. Generally, bridges are rated for three kinds of applied loads which are included design loads, legal loads, and permit loads [15,16,17,18].

Rating factor (RF) is the specific result of the analysis of bridge rating which is a mathematical application is used to evaluate the strength of the bridge structure. The rating factor is the ratio of the determined live load capacity of the bridge to the weight of the rating truck live load effects. When the rating factor is multiplied by the rating truck weight, it can be known as the rating load. Bridge rating is typically concerned only with the effects formed by live loads and dead loads. Forces is created by thermal effects, lateral wind loads, and longitudinal loads are not considered in rating analysis. A rating of 1.0 or higher means the bridge can safely carry the trucks loads [19,20].

The objectives of load rating analysis are to determine which structures have insufficient load capacity that may need posting or other remedial act, to determine the safe posting boundary for structures with insufficient load capacity, to evaluate the effective use of presented resources for rehabilitation, strengthening, replacement, and repairing, to evaluate the overload permit evaluation procedure [21].

Bridges are one of the significant civil structure which was made by civil engineers and they have excessive influence on society by supporting regional connection. There are many types of bridge structure and composite bridge is one of them. Composite bridges consist of steel girders concrete deck slab. They are less expensive and need less maintenance and less temporary structures for execution and by using assembled structural parts high speed construction can be completed. Composite bridge decks are often used in the combination with steel or concrete decks to equilibrium the weights [22,23].

Composite bridges are wide common all over the places of the world for the reason that they have several benefits of steel bridges with several important features of reinforced concrete bridges. Steel girder of I-section is the common and greatest active hard section to resist bending moment and shear forces. The flexural resistances of a steel girders are measured by four failure kinds. These kinds are flange local collapsing, yielding, web local collapsing, and horizontal torsional collapsing. Steel-concrete composite bridges offer an effectual and cost active system of others bridges erection. The bending resistance of the combined materials is significantly increased and it can be used long span when using the tensile strength of steel in the essential girder and the compression strength of concrete in the deck [17,24,25,26,27].

For bridge load rating, there are three various analysis method to assess the structural capacity of bridges. The first method is known as Allowable Stress Rating (ASR), the second method is known Load Factor Rating (LFR), and the third method is known Load and Resistance Factor Rating (LRFR). The comparison between these analysis method was showed in early researches which were depending on Rating Factor. It is a occupation of the design capacity, self-weight load, and traffic live load with different load factors [28].

The objectives of research are to assess and calculate the load capacity of composite bridge structural parts by using load rating analysis method under different types of international trucks and to calculate the factored static parameters such as factored bending moment, factored vertical shear force, factored axial force, and vertical displacement to check the load capacity of bridge members.

2. Bridge model and materials

Composite bridge model consists of two spans with total length is 40 m and each span has 20 m length. The width of bridge is 11 m. The type of supports is simply supported bridge. The number of piers is two piers with concrete cap beam. The bridge model is created by using CSI bridge Ver. 20 and this software uses finite element method in the analysis of bridge structure. The superstructure of bridge consists of five I-steel girders with 30 cm concrete deck. The steel girders are connected by using eight transvers steel diaphragms for each span. The number of lanes is two. The thickness of wearing surface of pavement is 10 cm. The concrete material grade is 4000psi, weight / volume is 23.5631 kN/m^3, modulus of elasticity is 24855.578 MPa, and Poisson ratio is 0.2. For steel girders, the material grade is 50, weight per unit volume is 76.9729 kN/m^3, modulus of elasticity is 199947.98 MPa, and Poisson ratio is 0.3. Fig. 1 shows the composite bridge model in four directions.

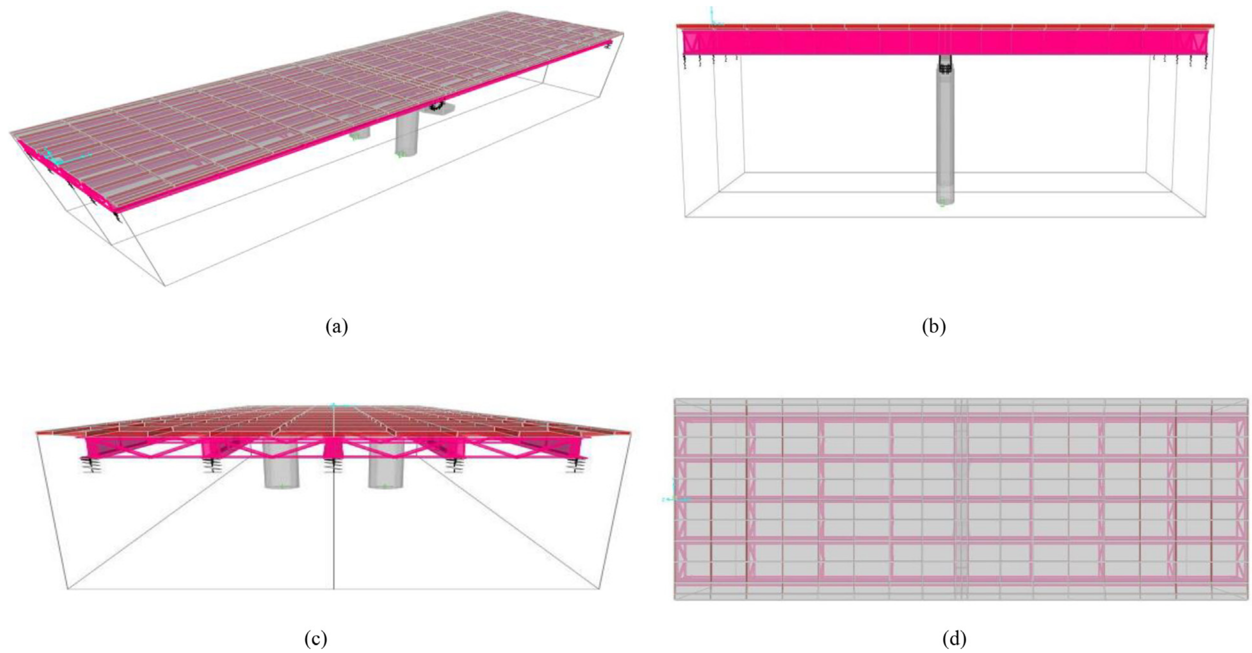

Fig. 1. Composite bridge model (a) three dimension view; (b) elevation side view; (c) front view; (d) top view.

Table 1
Different types of trucks.

Truck No.	1	2	3	4	5	6	7	8	9
Truck Name	HL-93M	AML	Hsn-44L	LM3-3600/240	Fatigue –III Truck	IRC70R	Ho (b)	CL3-625-ONT Truck	HB-HA1

3. Dead and live loads

Dead load of bridge structure is known as self-weight of all bridge structure elements such as girders, deck, wearing surface (flexible pavement layer), sidewalks and railings, parapets, stiffeners, signing, and other services. In this study, dead load of structure and wearing surface will be used in load rating analysis. The live load can be define as the load which it moves along the length of the bridge span and it represents by trucks loads. This study uses different type of trucks from different countries which they are depending as design truck load for analysis and design of bridges structures. Table 1 lists the different types of trucks.

4. Theory of load rating analysis

Finite element method is used in the analysis of load rating by using CSI-Bridge Ver. 20. The loads include dead load, truck live load, and wearing surface. The rating type is steel I comp. strength. Two types of results are dependent in this study. The first is for flexure and the second is for shear. Live load distribution to girder uses directly girder forces from analysis. The evaluation level of load rating factor is used operating level. Generally, the load rating is stated as a rating factor for an actual truck live load. The following equations are used to calculate the load rating of each structural parts and their joining which are applied to combination of loads for flexure and shear [16,28,29]

$$RF = \frac{C - A1D}{A2L(L + I)} \tag{1}$$

where C = capacity of the structural part, D = dead load of structural part, L = traffic live load passed, I = impact factor, A1 = factors of dead load, A2 = factors of live load.

$$RF = \frac{C - (\gamma dc)(DC) - (\gamma dw)(DW) \pm (\gamma p)(p)}{(\gamma L.L)(L.L + IM)} \tag{2}$$

where DC = dead load of structural part, DW = pavement load, P = permanent loads, LL = traffic live load, IM = dynamic load because if traffic live load, γdc = LRFD load factor of dead load, γdw = LRFD load factor of pavement load, γp = LRFD load factor for permanent loads, and γL.L = assessment live load factor.

5. Results of flexure rating

Fig. 2 illustrates the results of maximum and minimum load rating analysis for flexure rating. From this figure it can concluded that the left and right girders carry the higher values of flexure load rating for all types of trucks load. The higher value of maximum flexure rating is 342.87 Ton due to truck load type Hsn-44L. The lower value of maximum flexure rating appears within truck type LM3-3600/240 which is 38.51 Ton. The interior girder No.1 has higher value of flexure rating than interior girder No.2 except the value of truck load type Hsn-44L. The interior girder No.3 has same value of interior girder No.1. Figs. 3 and 4 shows the comparison results for different types of trucks loads on girders of composite bridge. Therefore, the structural member of bridge which are subjected to higher values of flexure load rating will have sufficient live load carrying capacity, more elasticity and stiffness, indicating

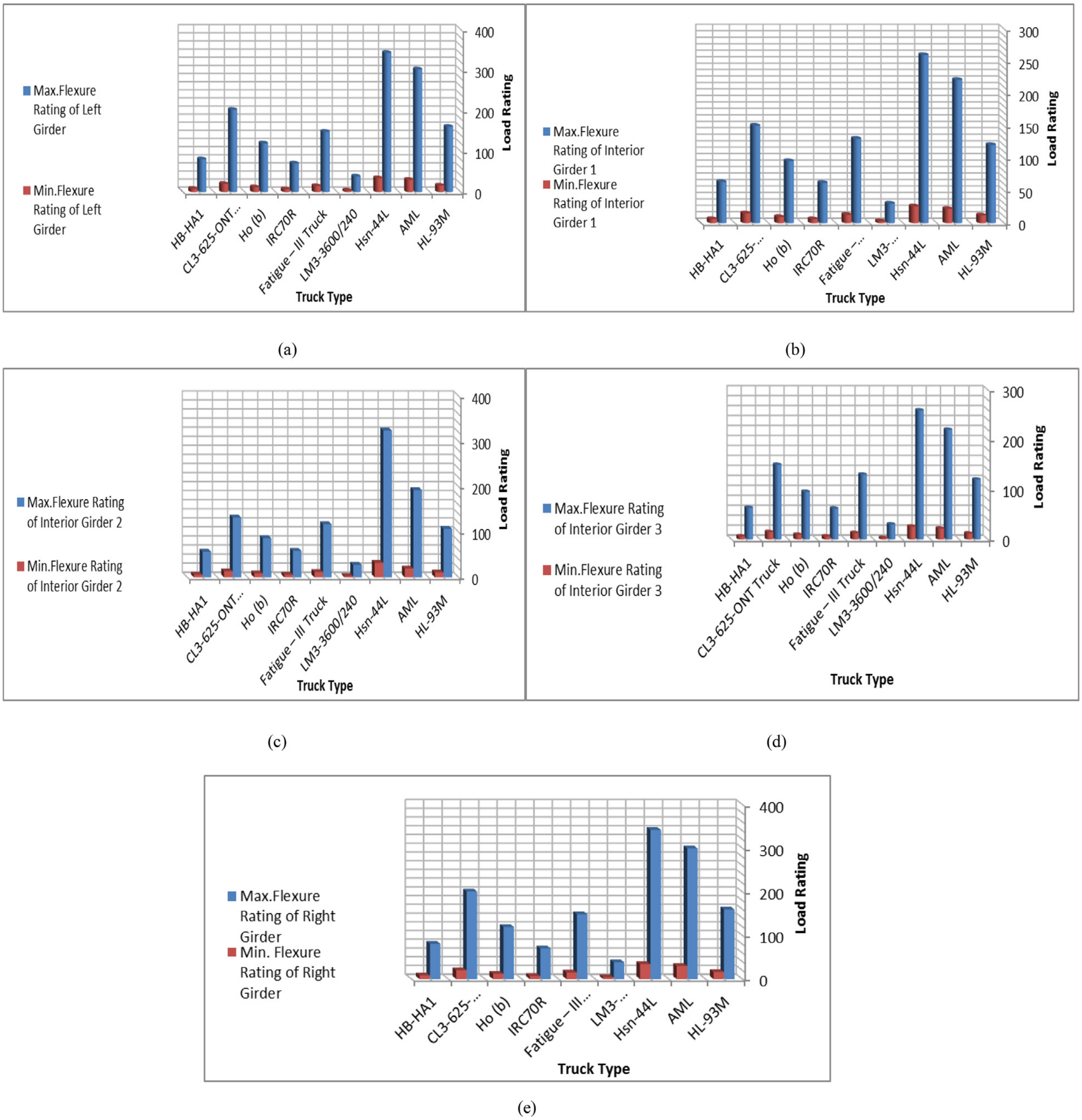

Fig. 2. Results of flexure load rating for bridge girder (a) maximum and minimum flexure rating for left girder; (b) maximum and minimum flexure rating for interior girder 1; (c) maximum and minimum flexure rating for interior girder 2; (d) maximum and minimum flexure rating for interior girder 3; (e) maximum and minimum flexure rating for right girder.

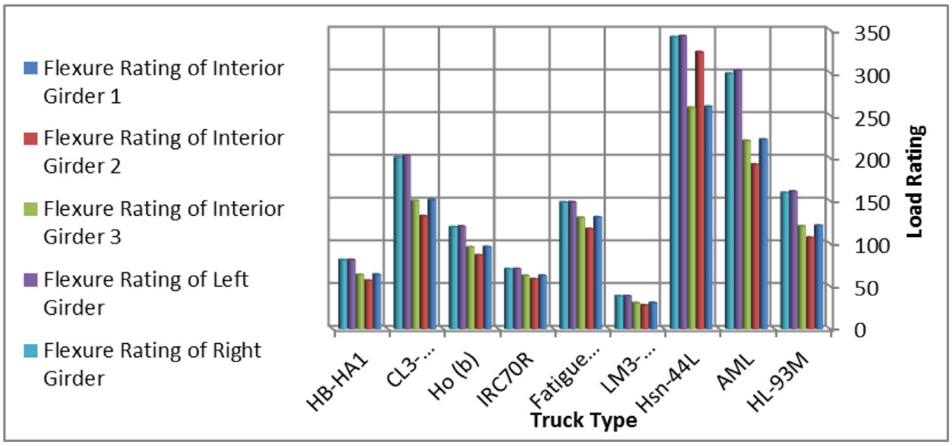

Fig. 3. Comparison of maximum flexure rating for girders of bridge.

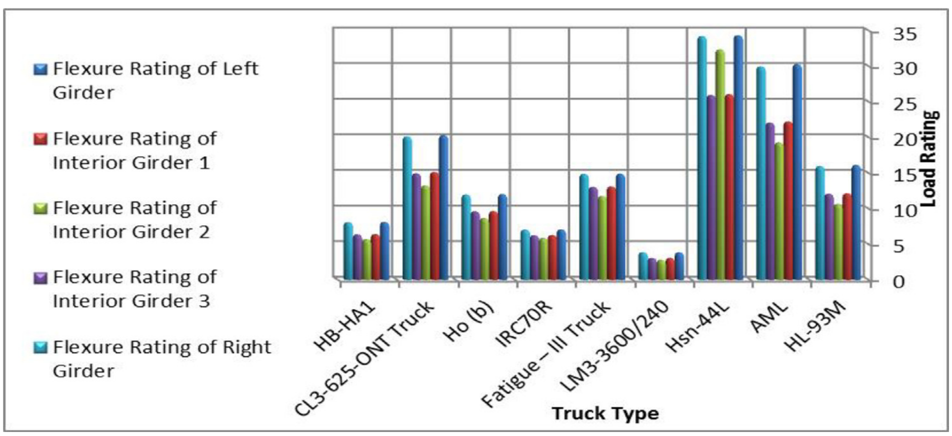

Fig. 4. Comparison of minimum flexure rating for girders of bridge.

that the values of static structural parameters such as bending moment, vertical shear force, vertical displacement and axial force are lower than structural member have minimum values of flexure load rating.

6. Results of shear rating

The results of shear load rating can be shown in Fig. 5. The maximum values of shear load rating are exist within exterior left and right girders of bridge superstructure and the higher value is 853.85 due to truck type AML. The minimum value is 95.05 due to truck type LM3-3600/240. For others interior girders No.1, No.2, and No.3, trucks types AML and LM3-3600/240 appear maximum and minimum values of shear load rating respectively. Indicating that the girders have higher values of shear rating will resist the shear stresses due to vertical shear force and they will have lower shear values under factored live load analysis. The higher values of shear forces will appear within girders have lower values of shear rating. Figs. 6 and 7 shows the comparison results of maximum and minimum shear rating.

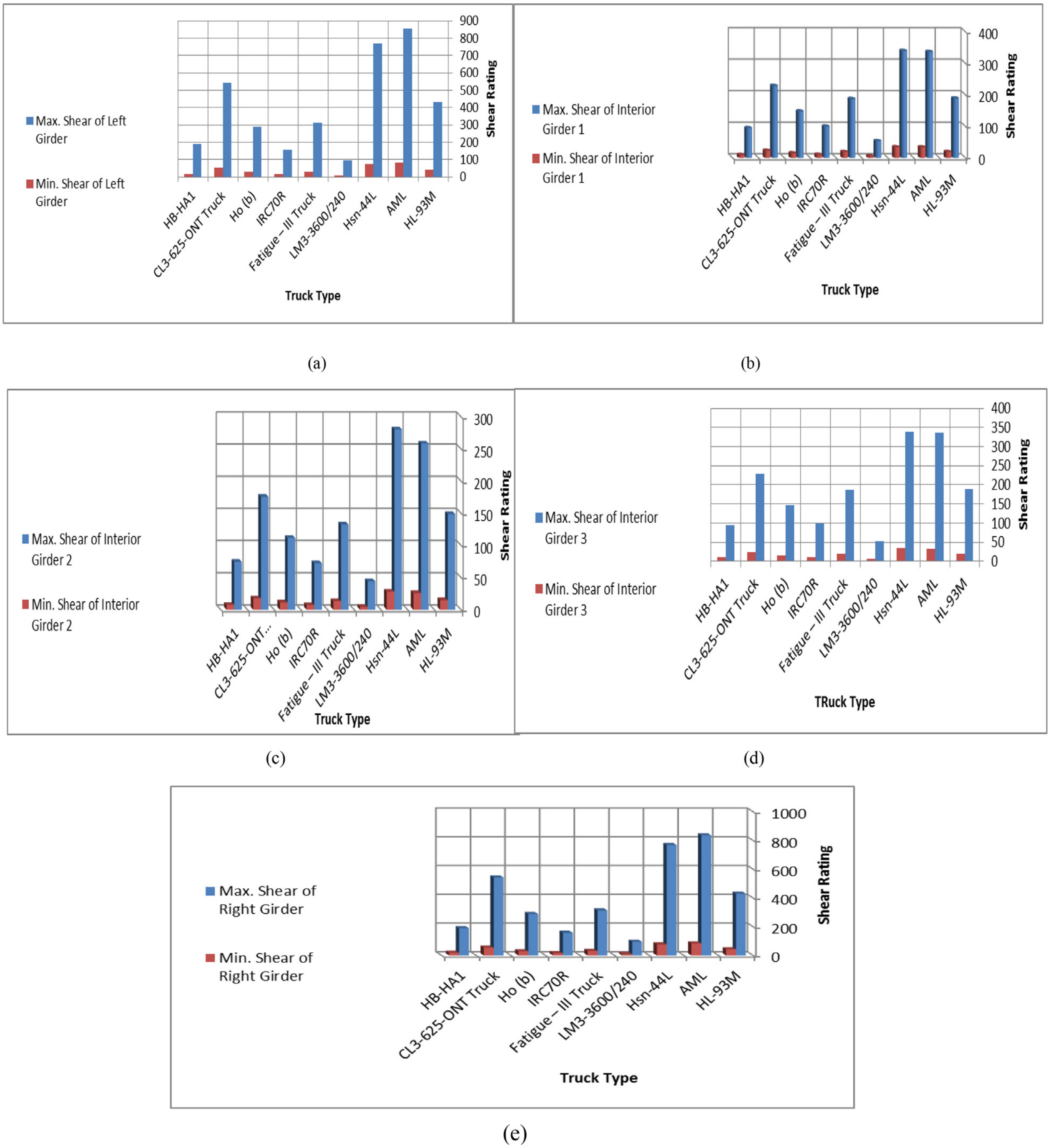

Fig. 5. Results of shear load rating for bridge girder (a) maximum and minimum shear rating for left girder; (b) maximum and minimum shear rating for interior girder 1; (c) maximum and minimum shear rating for interior girder 2; (d) maximum and minimum shear rating for interior girder 3; (e) maximum and minimum shear rating for right girder.

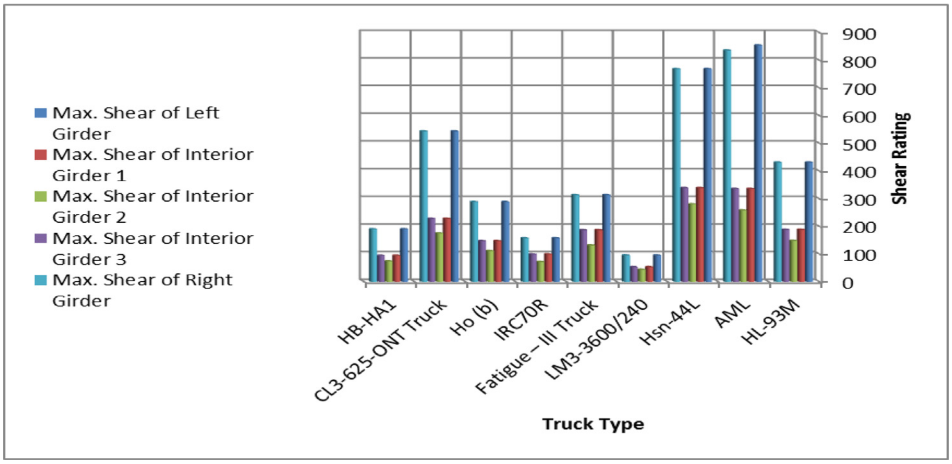

Fig. 6. Comparison of maximum shear rating for girders of bridge.

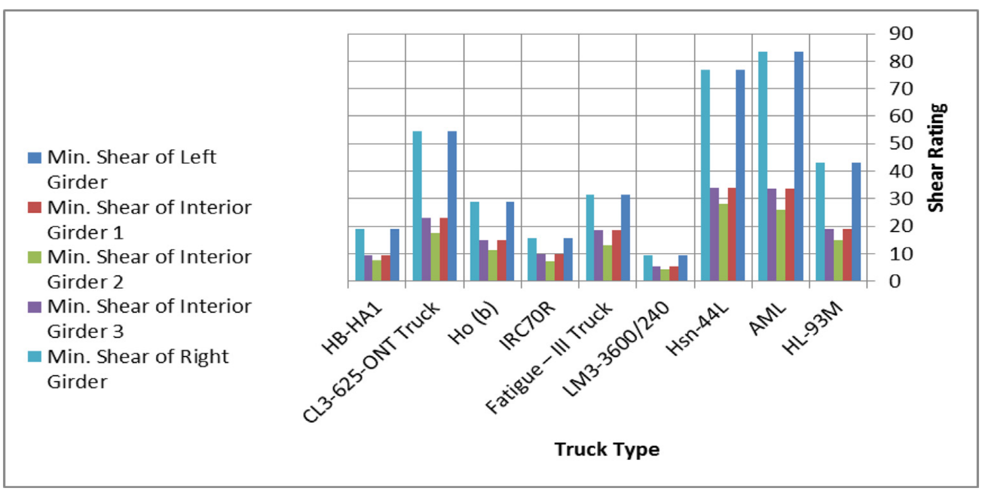

Fig. 7. Comparison of maximum shear rating for girders of bridge.

7. Results of factored live load analysis

Figs. 8, 9, and 10 show the results of factored bending moment, vertical shear force, and axial force respectively under effect of different trucks types by factored live load analysis. Form these figures, truck type LM3-3600/240 show the higher values of factored bending moment, vertical shear force, and axial force which are equal to 3445.3 kN m, 562.8 kN, and 373.2 kN respectively within exterior girders which are appeared minimum flexure load rating. The lower values of factored bending moment, vertical shear force, and axial force are existed under effect of truck type AML and Hsn-44L. The values are 439.4 kN m, 385.4 kN m, 64.01 kN, 69.61 kN, 39.8 kN, 46.8 kN respectively, because of these trucks has higher flexure and shear load rating. Fig. 11 shows the values of maximum vertical displacement under different trucks live loads along the bridge length. The maximum value is 29 mm under truck type LM3-3600/240 which has lower flexure load rating. Whereas, the minimum value of vertical displacement is 3 mm and 4 mm under effect of trucks type AML and Hsn-44L because of these types exit higher values of flexure and shear load rating.

8. Limitations and future scope of the study

This study represents a methodology for bridge load rating under traffic loads and it can be applied this methodology for others types of bridges structures such as prestressed and normal reinforced concrete bridges such as box girder bridges, cable-stayed bridges, suspension bridges, T-beam bridges, I-beam bridges.

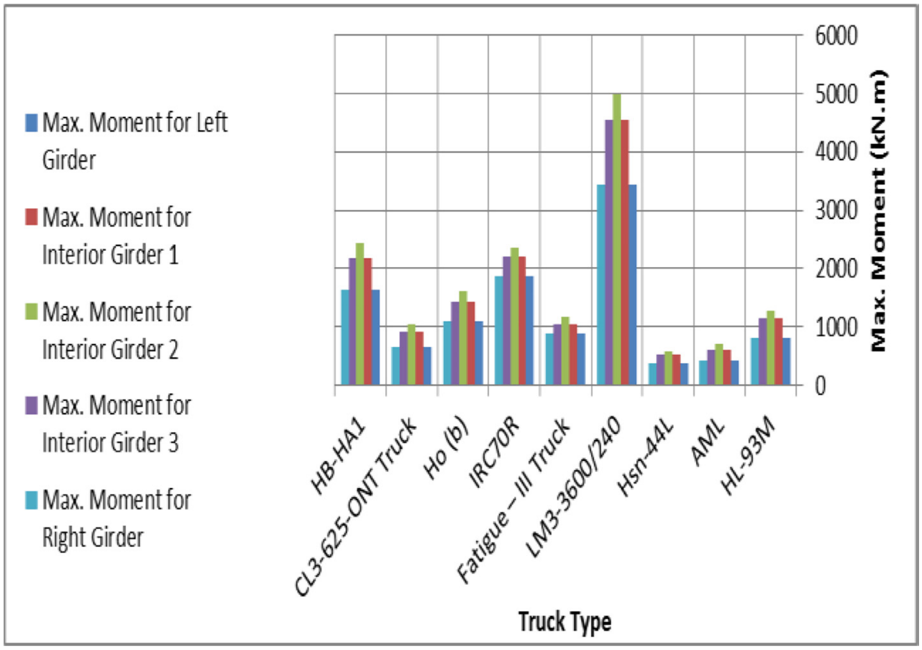

Fig. 8. Factored bending moment for girders.

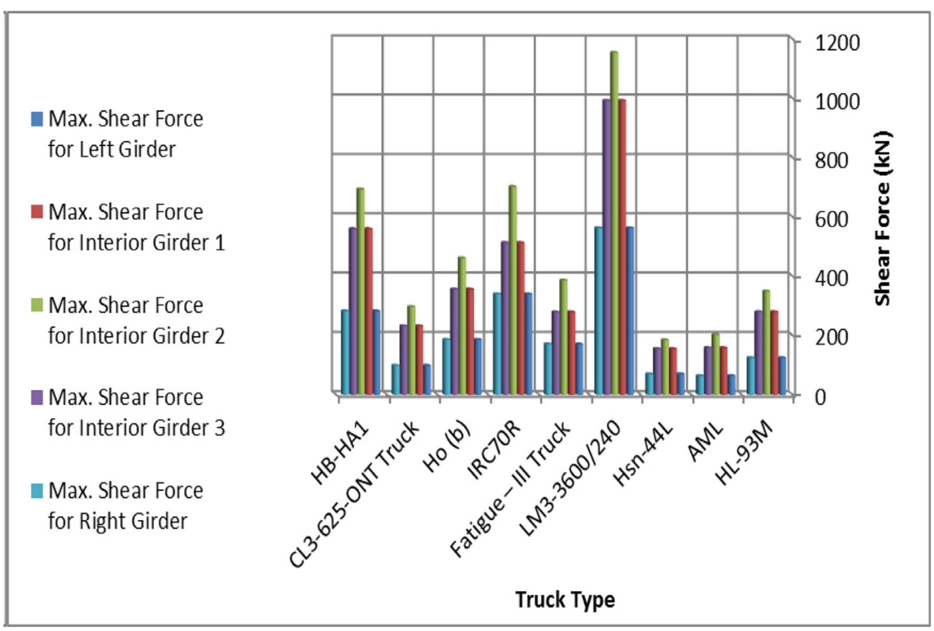

Fig. 9. Factored vertical shear force for girders.

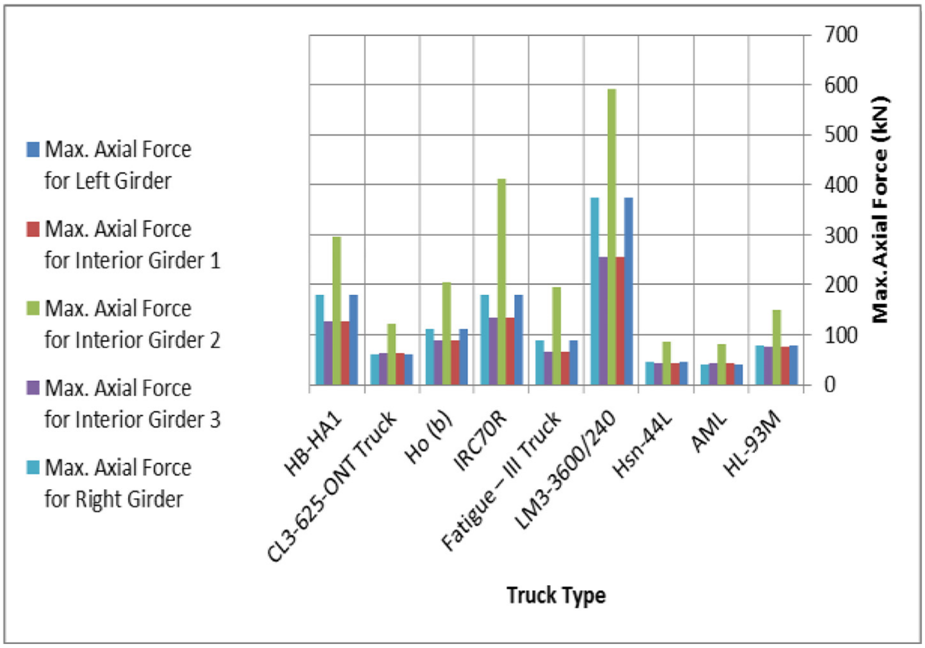

Fig. 10. Factored axial force.

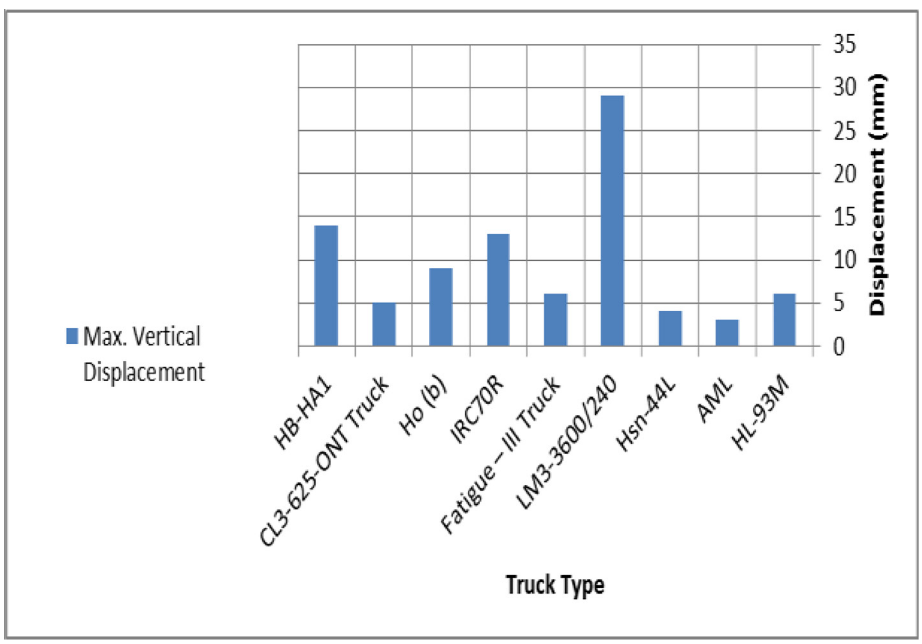

Fig. 11. Maximum vertical displacement under live load.

9. Conclusions

The results of flexure load rating shown that the left and right girders carried the higher values of flexure load rating for all types of trucks load. The structural member of bridge which were subjected to higher values of flexure load rating will have sufficient live load carrying capacity, more elasticity and stiffness, indicating that the values of static structural parameters such as bending moment, vertical shear force, vertical displacement and axial force were lower than structural member had minimum values of flexure load rating. The girders had higher values of shear rating will resist the shear stresses due to vertical shear force and they had lower shear values under factored live load analysis. The higher values of shear forces appeared within girders had lower values of shear rating. The results of factored bending moment, vertical shear force, and axial force shown that truck type LM3-3600/240 shown the higher values of factored bending moment, vertical shear force, and axial force within exterior girders which were appeared minimum flexure load rating. The lower values of factored bending moment, vertical shear force, and axial force were existed under effect of truck type AML and Hsn-44L because of these trucks had higher flexure and shear load rating. The maximum value of vertical displacement was 29 mm under truck type LM3-3600/240 which had lower flexure load rating. The minimum value of vertical displacement is 3 mm and 4 mm under effect of trucks type AML and Hsn-44L because of these types exited higher values of flexure and shear load rating.

CRediT authorship contribution statement

Ali Fadhil Naser: Conceptualization, Methodology, Software, Data curation, Writing – original draft. **Hussam Ali Mohammed:** Visualization, Investigation, Supervision. **Ayad Ali Mohammed:** Software, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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