Analysis of Nonlinear Deflection and Horizontal Distribution Coefficient of Reinforced Concrete T Beam Span Structure Subjected to Static Load of Motor Vehicle

Hieu, Duc Nguyen

University of Transport and Communications, No.3 Cau Giay Street, Lang Thuong Ward, Dong Da District, Hanoi, Vietnam.

Abstract: Heavy vehicle load causes damage and degrades bridges and roads, in which reinforced concrete T-beam span structures are widely used in bridges with short span lengths. The article clarifies the deflection and horizontal distribution coefficient of live load in operating conditions with normal and overloaded vehicle loads. They are using the finite element method for the nonlinear analysis of 3D span structures with full load-bearing components. Arrange the entire vehicle load on the span structure with different load levels based on the results of the actual vehicle weighing results and the assumed load. Responding to high load levels, cracked concrete, and mechanical properties of concrete including breaking characteristics according to mechanical failure theory. The reinforcement is simulated in detail and assumes complete adhesion to the concrete. The research results show the correlation between deflection and horizontal distribution coefficient of live load with vehicle load, which serves as the basis for proposing exploitation load as well as bridge design to withstand heavy vehicle load.

Keywords: Span structure, T-beam, reinforced concrete, nonlinearity, deflection, horizontal distribution, motor vehicle

I. INTRODUCTION

Reinforced concrete span structure is very popularly used in Vietnam as well as in the world [1] [2] [3]. According to the research results in the US [4] [5] [6] [7], the percentage of different types of common bridges in the US is shown in Figure 1, in which, the T-beam span structure accounts for 6.08% of the total types demand in general. In Vietnam, reinforced concrete beam span structures are often used for short spans [4].

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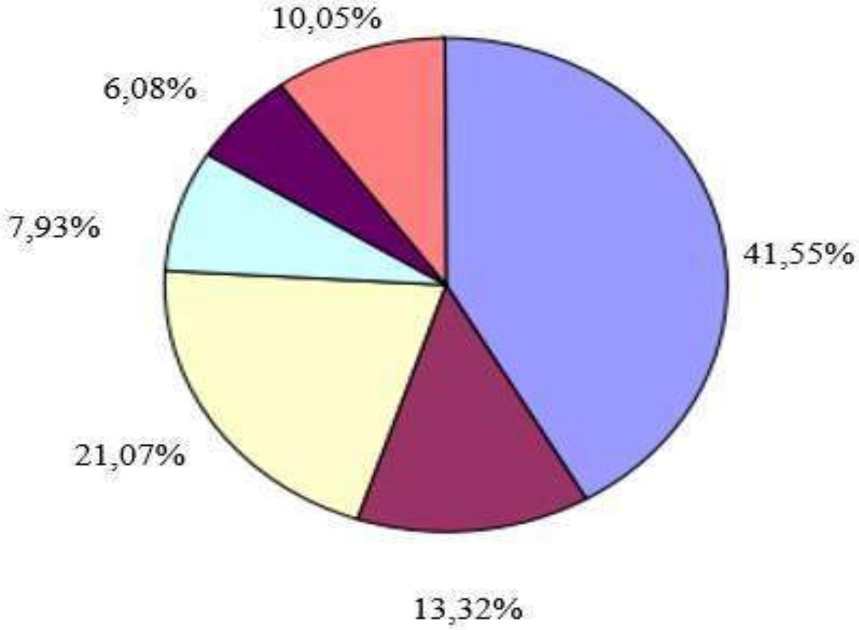


Figure 1. Types of bridge structures used in the US

The situation of heavy trucks still operating on the road is an ongoing reality in Vietnam due to many different reasons. Statistical results from weighing stations show that the axle load of heavy vehicles exceeds the specified limit and is even more than 2 times [1]. From research results in Vietnam and around the world [3], under the effect of overloaded vehicles, the cumulative damage in reinforced concrete span structures increases many times compared to exploitation with normal axle loads determined. Heavy trucks cause many serious problems for road and bridge systems and operating safety. In this study, the deflection and horizontal distribution coefficient of the T-beam span structure under the effect of heavy vehicle load will be clarified based on the results of the nonlinear analysis of reinforced concrete structure by specialized software according to the finite element method.

The horizontal distribution coefficient of a beam can be calculated as the ratio of the beam deflection to the total deflection of all the beams. The span structure appears to crack, reducing the stiffness of the structure, and leading to an increase in the deflection of the beams. The degree of cracking of the beams is different depending on the position of the beams and the vehicle load class. Therefore, when the vehicle load is increased, the deflection of the beams increases but is not uniform due to different degrees of cracking. This leads to a change in the horizontal distribution coefficient of the beams.

II. RESEARCH BACKGROUND

The object considered in this study is a reinforced concrete span structure with 1 lane. The span length is 9m, the bridge width is 4.5m, and the distance from the girder end to the center of the bearing is 0.2m. The reinforced concrete deck slab has a thickness of 175mm and rests on 3 supporting beams, beam spacing is 1.5m. The bridge deck is arranged with 2 reinforcing meshes, the upper and lower grids. Using D13 steel step reinforcement 150mm. The detailed structure can be seen in Figure 2.

½ Cross section at the middle the span ½ Cross section at the end span

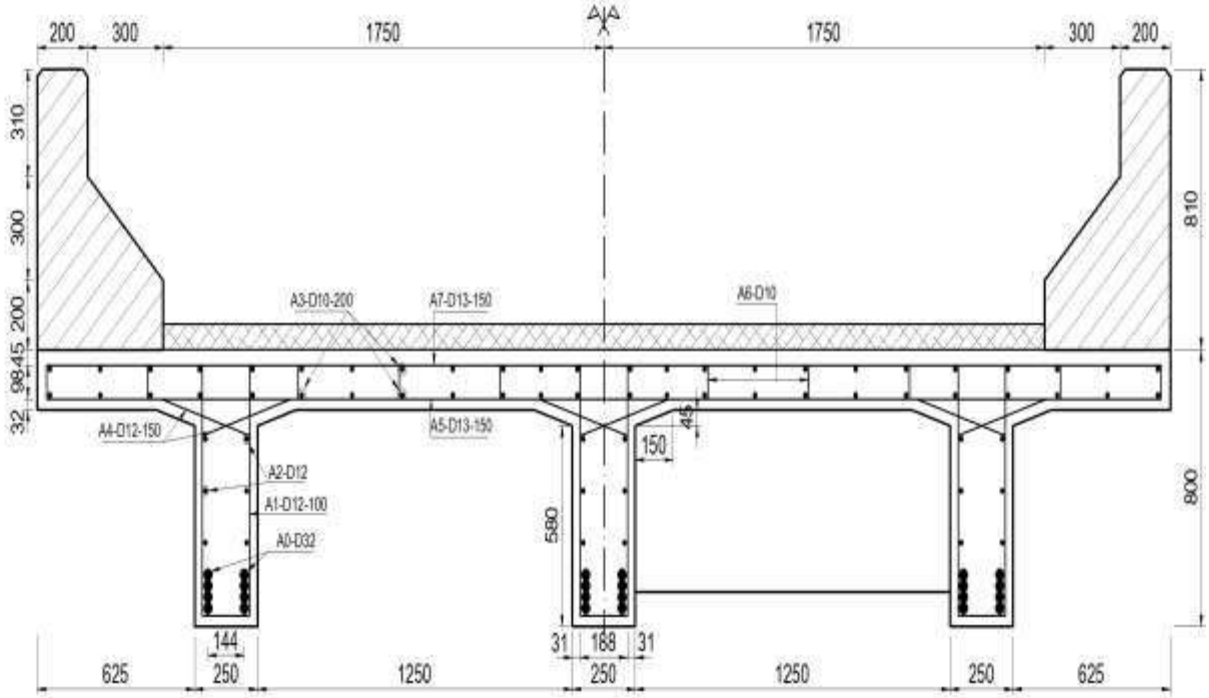


Figure 2. Detail structure of reinforced concrete span structure.

According to data at Dau Giay weighing station (Dong Nai province) [1], the highest percentage of overloaded trucks 2-axle trucks is over 20%, followed by 3-axle trucks and at least 5-axle trucks. shaft with more than 5%. The largest axle load recorded was over 25 tons of the rear axle of the 2-axle truck as shown in Figure 3. The maximum axle load of 50 tons was used in this study to evaluate the nonlinear behavior of the span structure under concrete the cardboard has cracked.

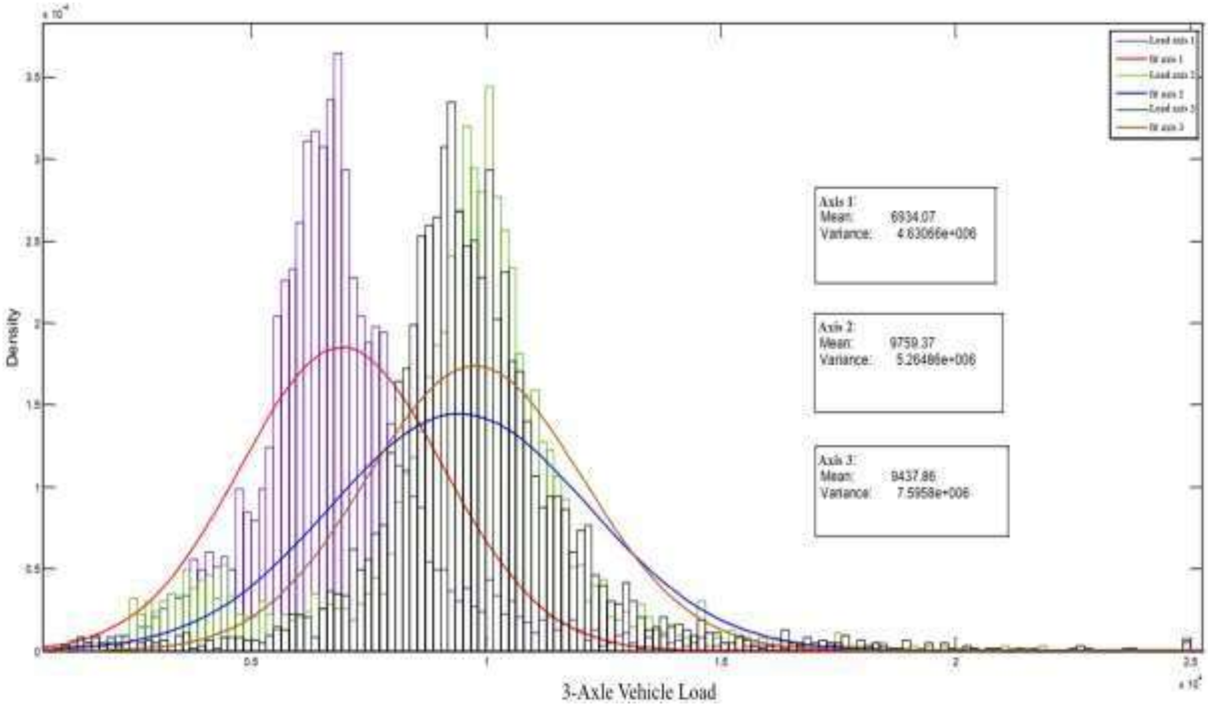


Figure 3. The load distribution density of 3-axle axles

III. METHODOLOGY

3D model of span structure with full load-bearing parts of span structure under the action of heavy truck 3 stacked in an unfavorable position for longitudinal girders and deck slab as shown in Figure 4.

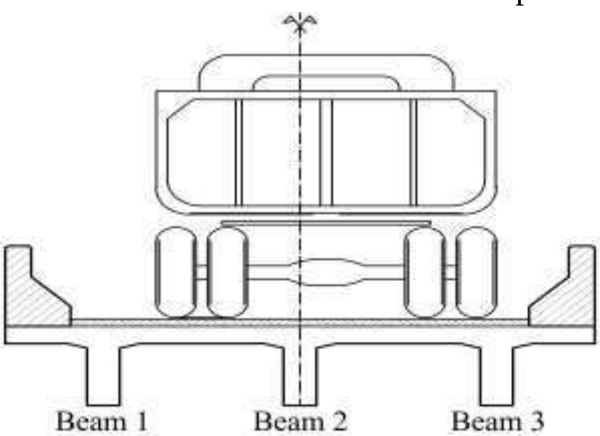
Active load:

The span structure is subjected to the simultaneous effects of dead and live loads. Static loads include the self-weight of the span structure, handrail, and deck coating. The live load is a 3-axle heavy truck [1] [5]. Place the vehicle at an unfavorable position for beams and deck slabs. In the longitudinal direction, the middle axle of the vehicle is the heaviest axle at the mid-span position; In the horizontal direction of the bridge, there is a row of wheels in the middle of the supporting beams as shown in Figure 4. During the analysis, the axial load of the truck under consideration is considered to increase gradually during the calculation to evaluate the behavior of the structure deck slab under the impact of overloaded vehicles.

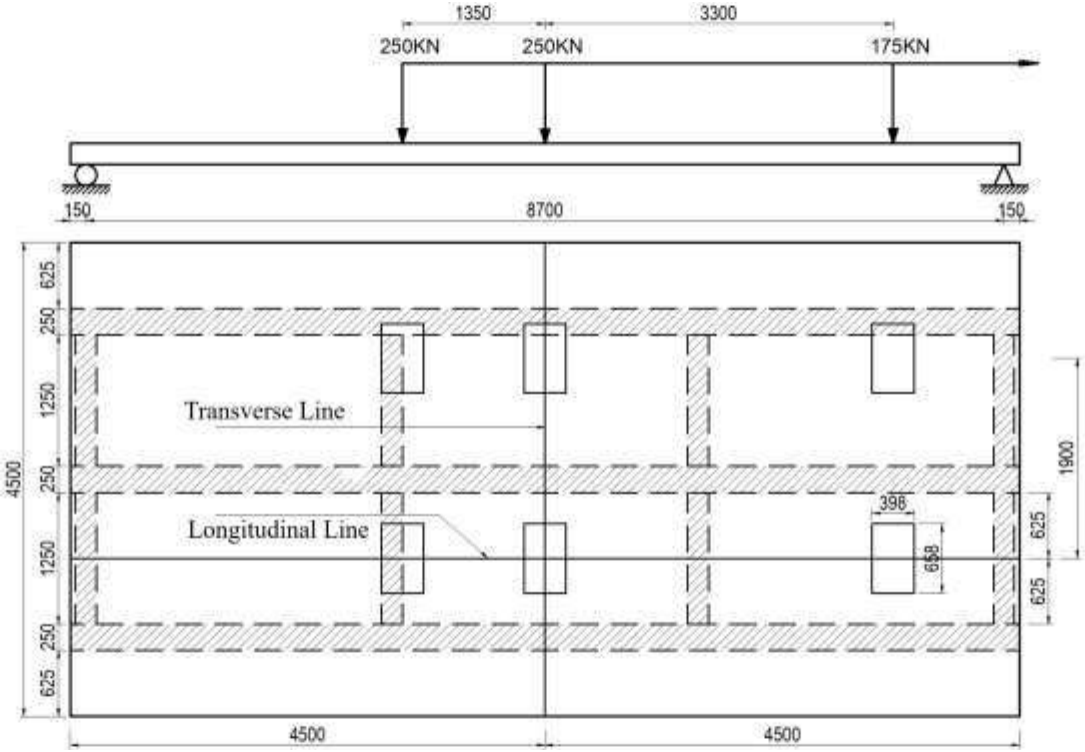
The uniformly distributed tire pressure is calculated as the wheel load divided by the contact area between the wheel and the bridge. The wheel load distribution is a rectangle measuring 658 x 398 (mm) considering the effect of a 74mm thick deck coating. In fact, when the vehicle is moving on the bridge, an additional shock force is generated in addition to the vehicle load. Convert the problem of vehicles moving on the bridge to the equivalent stationary stacker problem by multiplying the vehicle load by the shock coefficient. In the scope of this thesis, the shock coefficient is assumed to be equal to the current bridge design standard, 1+ IM = 1.33 [2]. Wheel pressure for 25-ton axle load:

$$q = \frac{25 \times 10 \times 1000 \times 1.33}{2 \times 658 \times 398} = 0,635 \ \text{N} / \text{mm}^2$$

In addition, the span structure is analyzed with the assumed axle load of up to 50 tons corresponding to the wheel pressure q = 1.27 N/mm2 to evaluate the nonlinear behavior of the span structure when the concrete has been poured cracked.



a - Arrange the vehicle horizontally on the bridge



b - Arrange the vehicle horizontally on the bridge

Figure 4. Unfavorable arrangement of vehicles on the bridge.

The physical and mechanical parameters of the material:

Mechanical and physical steel properties: The reinforcement behavior undergoes two phases of elasticity and flow. The analysis shows that this model has higher reliability when fully describing the working stages of steel and ensures that it does not affect the convergence speed of the analytical problem [9].

The reinforcement has the following physical and mechanical criteria: E = 200,000 MPa, Poisson coefficient v = 0.3, γ= 0.000785 N/mm^3, fy = 420MPa [2].

Assume that concrete is in tension according to Hordijk model, and in compression according to Thorenfeldt model as shown in Figure 4. Mechanical and mechanical properties of the materials are as shown in Table 1.

Table 1. Mechanical properties of concrete [2, 8]

Crack width, h	Initial cracking energy, G_f	Tensile strength, f_t	Elastic modulus, E	Volumetric weight, γ_c	Compressive strength, f'_c	Potentiation coefficient, ν
(mm)	(J/m^2)	(N/mm^2)	(Mpa)	N/mm^3	(N/mm^2)	
60	75	2,63	28110	0,0000232	30	0,2

Meshing elements:

Concrete elements: Divide the concrete block into block elements for 3-dimensional load-bearing block structures. The elements have an average size of 25x25x25(mm) for the deck slab. The longitudinal and transverse beams are divided into larger sizes to reduce the number of elements and the processing volume for nonlinear analysis.

Rebar element: Divide the reinforcement into bar elements, each with a length of 25mm. In addition, the model considers the common working of reinforcement and concrete with the assumption that the reinforcement has completely adhered to the concrete.

Figure 5. Finite element method meshing model

IV. ANALYSIS RESULTS

Calculation results of the deflection of beams at a mid-span position corresponding to the maximum assumed axial load of 50 tons are shown in Figure 6. The relationship between the deflection of beams and axial load is shown in Figure 7.

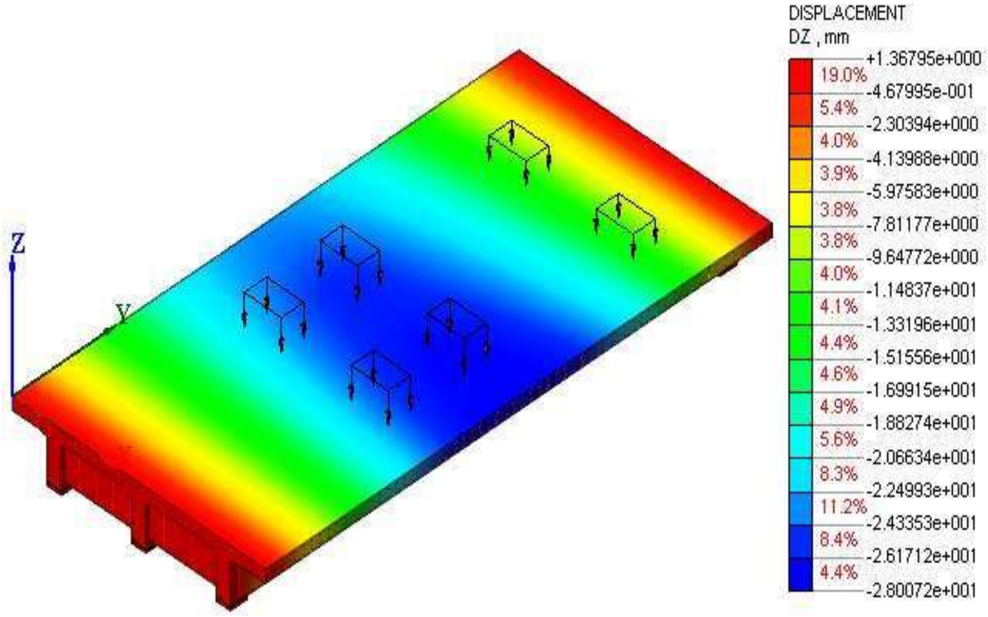


Figure 6. Results of calculating the deflection of span structure corresponding to axial load of 50 tons

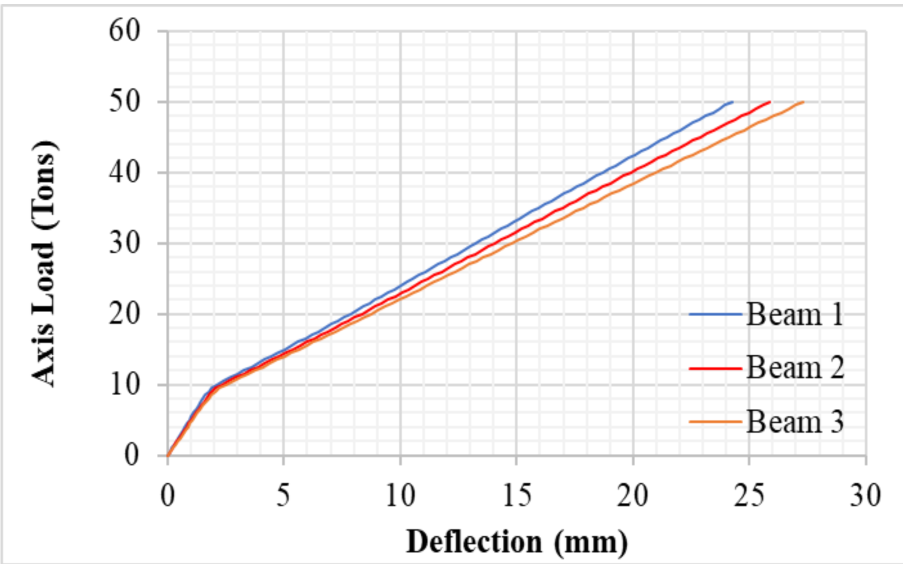


Figure 7. Structural deflection according to axle loads

Allowable deflection of span structure according to bridge design standards [2]:

$$[\Delta] = Ltt/800 = 8700/800 = 10.88 \text{ (mm)}$$

Corresponding to the axial load level of 24 tons, the maximum deflection in girder 3 is 11.13mm, which is larger than the allowable deflection. With an axle load of 25 tons recorded at the weighing station corresponding to the span structure under investigation, the deflection exceeded the permissible limit [1].

The effect of deflection when increasing one level of axial load by 0.5 tons is calculated as the deflection at the current load level minus the deflection of the previous bag and is called the deflection increment as shown in Figure 8. From the results, The analysis shows that the amount of deflection is constant corresponding to the period of the linear elastic working structure, uncracked concrete. When the axial load is > 6.5 tons, beam 3 is the beam with the largest deflection, the amount of deflection begins to increase because the beam concrete begins to crack, and the structural stiffness begins to decline. At the next load levels, the amount of deflection increases very quickly due to the large cracks forming, causing the structural stiffness to drop suddenly until it stabilizes at the load level of 10.5 tons. The survey process with an axial load from 0 to 50 tons shows that the load and deflection relationship curve has 2 branches with different slopes as shown in Figure 7. The branch at the beginning of the curve has a steep slope corresponding to the load < 6.5 tons and the remaining branch has a slight slope corresponding to the bag> 10.5 tons. Between the two branches, there is a transition curve corresponding to the axial load from 6.5 tons to 10.5 tons.

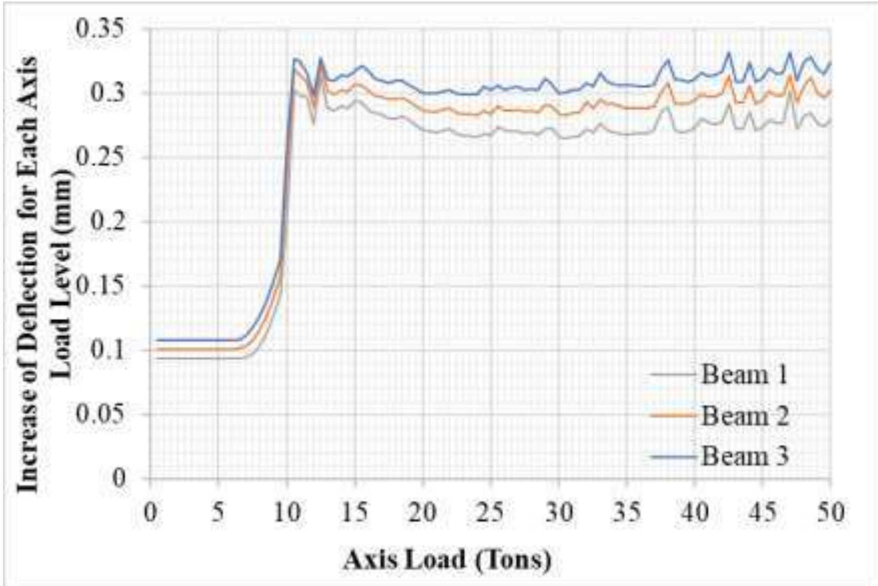


Figure 8: Structural deflection increments according to axle load class

Considering the horizontal distribution coefficient of beams, the beams have the same size, so the horizontal distribution coefficient of a beam is equal to the deflection of that beam divided by the total deflection of the beams. The results of the horizontal distribution coefficients of the zone beams with load levels are shown in Figure 9:

Axial load <6.5 tons: The horizontal distribution coefficient of the beams is constant, specifically, girder 1 is 0.3087, girder 2 is 0.3348, and girder 3 is 0.3565.

Axial load increased from 6.5 to 10 tons: The horizontal distribution coefficient of girders 2 and 3 increased, girder 1 decreased, and girder 2 increased insignificantly. There is a redistribution of live loads in the beams, the horizontal distribution coefficients in girders 3 and girders 1 are increasingly different.

Axial load increases from 10 to 21 tons: The horizontal distribution coefficient of girder 1 and girder 3 come closer together. The live loads are distributed fairly evenly in the beams.

Axial load increases from 21 to 50 tons: The horizontal distribution coefficient of girder 1 decreases, girder 3 increases while girder 2 is stable.

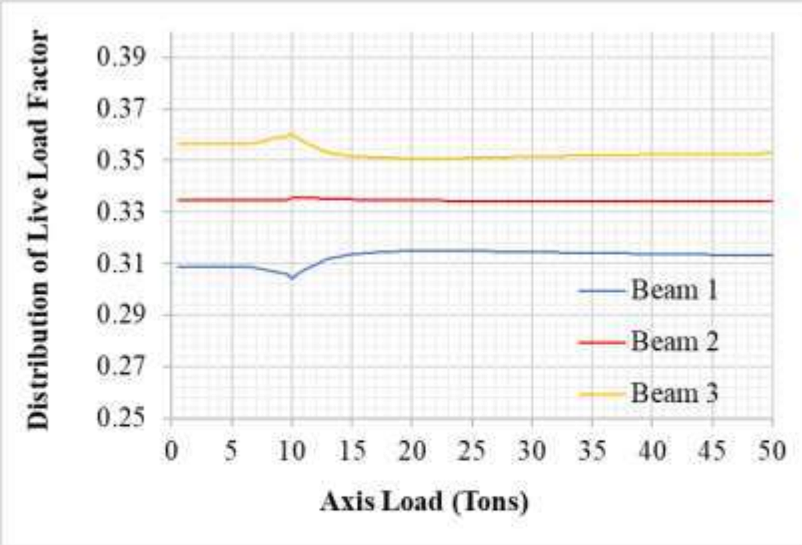


Figure 9: Horizontal distribution coefficient according to axle load class

V. CONCLUSION

The deck slab is cracked at the axial load level of 19.5 tons. Under the action of a heavy truck with a 25-ton axle, the deflection exceeds the allowable limit.

The horizontal distribution coefficient of the beams depends on the load classes. When the beams appear cracks and crack propagation, the live loads are redistributed between the beams. When the applied load is large corresponding to the large cracks developed in the beams, the distribution of live loads between the beams has little change.

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