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LOADS ON BRIDGES - OVERVIEW

BY

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Abstract. Bridges are always subjected to different types of loads, which can be divided into three big categories: vertical loads, transversal loads, and longitudinal loads. The primary function of a bridge is to have good performance under heavy loads represented by cars, trucks, trains and sometimes tanks. The aim of this paper is to provide an overview regarding types of loads that can appear on bridges with the main focus on loads generated by vehicles. This description will contribute to our future studies. We aim to develop future research and perform different types of stress calculations on the Octav Băncilă passage from Iaşi (Romania). Finite element analysis will be conducted on vehicle loads generated by trucks, which act on the bridge structure, simulating different loading scenarios. Based on the values of the stress calculations, we will highlight dangerous sections and take measures to enhance the reliability degree of the analyzed bridge.

Keywords: reliability, finite element, stress, vehicle, trucks.

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1. Introduction

Bridges are commonly used in cities and highway systems because they provide good efficiency for transport systems and travel between different cities and countries. They can be classified based on several criteria, including the materials used for construction, the purpose of construction, the intended duration of use, and the construction method employed. Bridges are constructed using a variety of materials such as steel, reinforced concrete, stone, brick, wood, and others (Aziz, 2019).

The primary reasons for bridge failures are attributed to construction mistakes, hydraulic issues, design errors, overloads and collisions. To minimize the risk of bridge failure caused by excessive loads, it is crucial to ensure that bridges are equipped with adequate protection measures. These provisions play a pivotal role in reducing the probability of structural failures when subjected to extreme loads (Guojing *et al*., 2022).

Finite element methods (FEM) have gained significant popularity in recent times due to their exceptional capability to simulate and evaluate the efficiency of structures. ANSYS, along with other software applications, is widely employed to implement FEM, enabling engineers to conduct comprehensive simulations and evaluations. By leveraging FEM and software tools like ANSYS, engineers can gain valuable insights into the structural behavior and performance, both during the design and construction phases, as well as throughout the lifespan of the structure (Tirpathi and Talawali, 2018; Qassim and Ali, 2020; Icke and Margheriti, 2010).

Different analysis on bridges like: vehicles weight influence, seismic-vibrations resistance, fire resistance and shear force resistance were conducted by other authors using finite element methods (Gang *et al*., 2017; Zhan and Xiedong, 2010; Gang *et al*., 2019; Xue *et al*., 2020; Zhen *et al*., 2021).

The constructor can perform various stress calculations to determine the reliability degree of the analyzed bridge, if all these types of loads are known. Based on the correctness of these calculations, the bridge can be exploited in safe conditions for a specified period of time. The ability of a bridge to withstand these loads is crucial to ensure the safety of the users and the longevity of the structure.

Our paper will primarily focus on analyzing the various loads that bridges encounter, with special focus on the loads generated by trucks. We will investigate how these loads influence the safety of the bridge throughout its service life because we aim to develop future research and perform different types of stress calculations on the Octav Băncilă passage in Iași - Romania (Scutaru, 2019).

The ANSYS software will be utilized to conduct finite element analysis on vehicle loads induced by trucks. This analysis will simulate various loading scenarios to assess their impact on the bridge structure. Based on the results of the stress calculations, we will establish the reliability degree of the bridge and higlight the dangerous sections of the structure.

2. Loads on Bridges

Bridges are always subjected to different types of loads, which can be divided into three big categories: **vertical loads**, **transversal loads**, and **longitudinal loads** (Table 1). For the first category, representative loads include dead loads, live loads, and impact. The second category is described by loads such as earthquakes, wind, centrifugal force, and lateral shock. Longitudinal loads are often described by loads like friction, wind, thermal, earthquakes, and braking (Aziz, 2019).

Table 1
Loads on bridges (Aziz, 2019)

Loads on Bridges	
Vertical	*Dead Loads*
	Live Loads
	Impact
Transversal	*Wind*
	Earthquake
	Lateral Shock
	Centrifugal
Longitudinal	*Wind*
	Earthquake
	Braking
	Thermal
	Friction

The following loads are having an important influence on the bridge structure (Aziz, 2019):

2.1. Permanent loads - refer to the loads that persist and exert force on a bridge throughout its lifespan. These loads can be categorized into three main types (Aziz, 2019):

2.1.1. Dead load – is represented by deck slab, stiffeners, beams or girders, floor beam, connection plates etc.

2.1.2. Superimposed dead load - this covers a range of elements on the bridge, including the surfacing (asphalt pavement), guardrails, sidewalks (footpath), handrails, lighting poles, cables, pipes, water lines and other utilities.

2.1.3. Pressures – permanent loads also include pressures caused by earth or water. Although these loads mainly affect substructure components (abutment, piers, footing etc.). They may also affect superstructure elements (wearing surface, deck, primary members, secondary members etc.) (Aziz, 2019).

2.2. Temporary loads - refer to the loads that are applied to a bridge for a brief period. While dead loads are the primary permanent loading condition, live loads are the major temporary loading condition (Aziz, 2019).

2.2.1. Live loading on highway bridge - the expression "live load" is making reference to a load that is passing the entire length of a bridge span. Thus, vehicles and peoples that are passing the bridge are noted to be live loads. To model the live load on a structure accurately, hypothetical design vehicles based on truck loading were developed (Aziz, 2019).

2.2.2. Earthquake loading – is a result of seismic forces that depends on the geographical position of the bridge.

Bridges must be constructed to ensure safety under the request imposed by "MCE", which is defined as maximum considered values for the earthquake (Aziz, 2019).

The bridge owner may require higher levels of performance to provide post-earthquake access to emergency facilities or to minimize the economic impact of service restoration time. In regions with seismic activity, this type of load is playing a big role when the bridge is designed.

Earthquake level is hinge on acceleration coefficient. Bridges that have values bigger than 0.19 for this coefficient, are considered to be located in regions with intense earthquakes. The coefficient mentioned above is employed to designate a seismic performance category (SPC) for the bridge. The single-mode spectral analysis is the most commonly utilized approach to compute the loading on a bridge induced by earthquake forces, based on SPC and the number of spans. (Aziz, 2019).

The single-mode spectral analysis method supposes loading in the fundamental transverse and longitudinal directions, as shown in the Fig. 1.

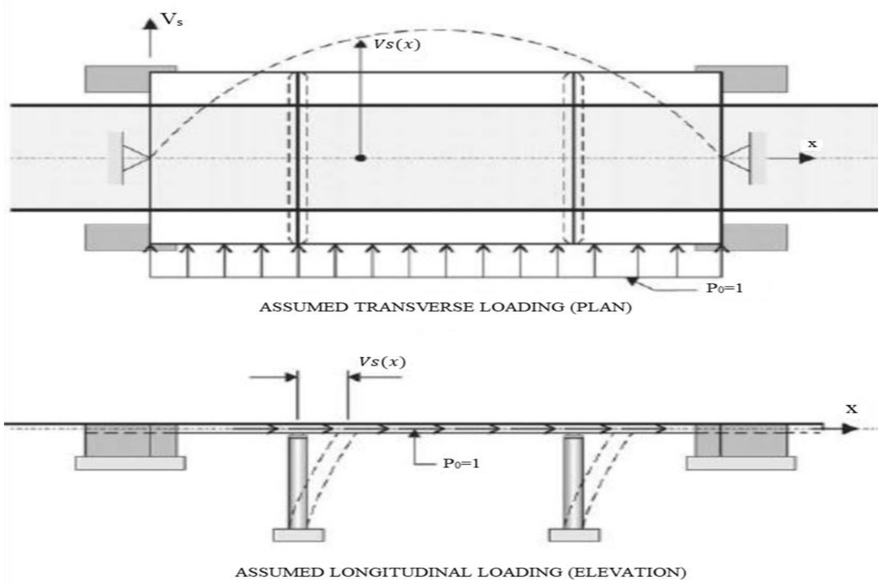

Fig. 1 – Single-Mode Spectral analysis – assumed loading (Aziz, 2019).

For regular bridges with multiple spans, the single-mode spectral analysis method for computing equivalent static earthquake loading is executed. The single-mode spectral analysis technique applies the same approach to evaluate both transverse and longitudinal earthquake loading. This approach is based on the principle of virtual displacements, which allows the development of a model regarding the bridge shape. To cause an initial displacement (V_s), a uniform static loading (P_0) is placed on length of the bridge structure. By combining the displacement with the dead load weight of the superstructure, it is possible to calculate the resultant earthquake loading. The first step is to determine the initial displacement of the model. This one is computed with an arbitrary unit load (P_0=1). After that, the dead weight value W(x) is determined (Aziz, 2019; Zhang *et al.*, 2014).

The dead weight value represents the weight of the bridge's superstructure as well as any parts of the substructure that contribute to the overall weight of the bridge. After obtaining the values of (V_s) and W(x), it is possible to calculate the following three factors (Aziz, 2019; Zhang *et al.*, 2014):

$$\alpha = \int_0^L Vs(x) * dx \quad (1)$$

$$\beta = \int_0^L W(x) * Vs(x) * dx \quad (2)$$

$$\gamma = \int_0^L W(x) * Vs(x)^2 * dx \quad (3)$$

Using the aforementioned factors, it is possible to compute the fundamental period of the bridge vibration (T) using the following formula (Aziz, 2019; Zhang *et al.*, 2014):

$$T = 2\pi \sqrt{\frac{\gamma}{g * K}} \quad (4)$$

where: **K** represents the lateral stiffness of the bridge; **g** is gravitational acceleration; **γ** represents the dead load of the bridge superstructure.

Next, we can proceed with the calculation of the horizontal earthquake loading acting on the structure. This loading can be expressed as a function of various parameters such as the mass of the structure, acceleration coefficient, fundamental period and soil type (Aziz, 2019; Zhang *et al.*, 2014).

AASHTO (standard) offers an elastic seismic response coefficient (C_S) that incorporates these parameters into a dimensionless value. This coefficient greatly simplifies the analysis by eliminating the need for the designer to compute an overall site period. The coefficient is defined as follows (Aziz, 2019; Zhang *et al.*, 2014):

$$C_s = \frac{1.2 * A * S}{T^{\frac{2}{3}}} \leq 2.5 * A \quad (5)$$

where: **A** represents the acceleration coefficient taken from acceleration coefficient map; **S** represents the soil coefficient based on soil profile type from the Table 2 and **T** is period of the bridge calculated above.

Table 2
Coefficient site values (Aziz, 2019)

Soil profile type	Site coefficient (S)	*Description*
I	*1.0*	*This refers to any type of rock, including shale-like or crystalline rock, as well as stiff soils such as sands, gravels, and stiff clays, that are present to a depth of less than 60 meters above the underlying rock.*
II	*1.2*	*This refers to stiff cohesive soils or deep cohesionless soils that exist to a depth greater than 60 meters above the underlying rock.*
III	*1.5*	*This refers to soft to medium-stiff clays and sands that are characterized by a layer of at least 9 meters of clay, with or without intervening layers of sand.*
IV	*2*	*This refers to soft clays or silts that have a depth of more than 12 meters.*

Once the values from Eq. (1) through Eq. (5) have been obtained, it is possible to calculate earthquake loading intensity. This loading presents an estimation of the inertial effects and can be expressed as follows (Aziz, 2019; Zhang *et al*., 2014):

$$P_e(x) = \frac{\beta c_s}{\gamma} W(x) V_s(x) \tag{6}$$

The earthquake loading is applied to the structure in the same manner as the application of the initial unit loading (P_0=1). Values for $P_e(x)$ are replaced to calculate displacement values, moments and shear forces. It should be noted that seismic analysis is not required for single span bridges (Aziz, 2019).

2.2.3. Wind loading – presents a complex set of loading circumstances that need to be simplified for practical design, similar to earthquake loading.

The wind forces present a dynamic issue but can be considered as static load which is uniformly distributed over the unprotected areas of the bridge. AASHTO specifies the bridge loading caused by these forces based on an assumed wind velocity of 160 km/h. In the case of conventional girder/beam type bridges, this wind velocity translates into an intensity of 2.40 kN/m², with the minimum total force being 4.38 kN/m^2.

The design wind pressure on vehicles is calculated by taking into account a wind velocity of 88.5 km/h. This wind velocity is applied to a long row of vehicles arranged in a random sequence. As a result, there is a wind pressure value equal with 1.46 kN/m^2. This pressure acts perpendicular and also at 1.8 m above the deck of the bridge. The load resulting from the wind pressure on the vehicles should be transferred to the substructure of the bridge (Aziz, 2019).

For conventional slab-on-stringer bridges with span lengths of 38m or less, AASHTO Standard Specifications permit the use of simplified wind loading (Aziz, 2019).

2.2.4. Channel forces - refer to the loads that a structure experiences due to water course-related features, such as stream flow, floating ice, and buoyancy. These forces primarily affect the substructure elements of the bridge, similar to seismic forces (Aziz, 2019).

Stream Flow: structures that have supports in water courses are vulnerable to supports sliding or overturning due to stream flow forces. Excessive stream flow velocities can cause adverse scour conditions, which can undermine footings and compromise the structure's integrity. The pressure caused by stream forces is typically a result of the change in momentum of water as it impacts a pier and then moves away from it. ASHTO Standard Specifications provide a definition for the average pressure acting on a bridge pier due to flowing water, which is as follows (Aziz, 2019):

$$P=K*(V)^2 \quad (7)$$

where: **P** is average stream pressure; **V** represents the average velocity of water and **K** is a constant based on pier shape.

Ice Load: highway bridges in cold weather climates are at risk of severe damage caused by ice floes and ice sheets impacting substructure, as well as static pressure due to thermal movements of ice sheets. In bridges with low clearance, the superstructure elements can also be impacted by ice loads. The influence of this loading is dependent on both the characteristics of the ice mass and the surface area of the pier with which it comes into contact. Typically, a supposed value of 20 kN/m^2 is used for the ice pressure. As part of the design process, it is necessary to determine the thickness of the ice locally (Aziz, 2019).

Buoyancy: bridges that have components, such as piers, submerged underwater can sometimes experience the effects of buoyancy. This is typically only a concern for very large hollow structures (Aziz, 2019).

2.2.5. Longitudinal forces - this force is called by AASHTO standard specifications like a braking force generated by the truck's wheels when breaking (Aziz, 2019).

2.2.6. Centrifugal forces - to ensure the structural integrity of constructions on horizontal curves, it is essential to compute the influence of centrifugal force. Similar to the longitudinal loading, the centrifugal loading mimics the movement of a vehicle traveling on the bridge, but in this case, it follows a curved path (Fig. 2). The force is considered to apply horizontally, at a distance of 1.8 meters above the deck level, and perpendicular to the centerline of the bridge (Aziz, 2019).

The definition of the force is as follows (Aziz, 2019):

$$C = 6.68 * S^2/R \quad (8)$$

where: **S** represents the design speed and **R** is the radius of curvature.

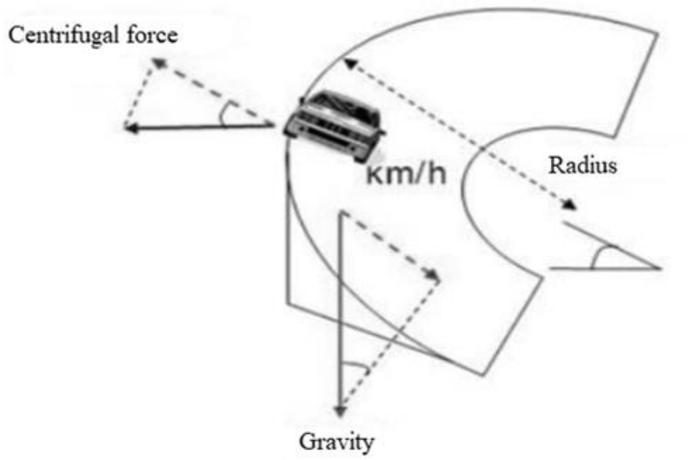

Fig. 2 – Centrifugal force (Aziz, 2019).

This force (C) is applied to the live load on the structure and, when multiplied by this load, determines the force to be exerted over the deck surface at a height of 1.8 meters. To generate the maximum forces in the bridge, one standard design truck is placed in each traffic lane (Aziz, 2019).

2.2.7. Impact (Dynamic load allowance) – the dynamic factor is generated by a vehicle traveling across a bridge. This factor is playing an important role for live load forces in dynamic analysis of bridge vibration simulation (Aziz, 2019).

2.2.8. Construction loads - during the building process of a structure, it is possible that various members may come under loading conditions induced by construction equipment or other types of loads. If such situations are foreseen during the design process, such as in staged or segmental construction, the designer should account for these additional loads and provide any necessary bracing or support structures on the plans (Aziz, 2019).

2.2.9. Thermal forces - designers should not underestimate the impact of thermal forces on a structure, as they can cause overstress, buckling, or cracking due to restraint. To account for temperature variations, provision should be made for expansion and contraction, and in the case of concrete structures, also for shrinkage. Thermal forces typically arise from temperature changes, either from hot to cold or from cold to hot. They can also be caused by structural redundancies or bearing failures (Aziz, 2019).

All the loads and factors presented above play a critical role in the degree of reliability of the bridge. By taking into consideration all of these factors, the constructor can perform various simulations to identify and counteract dangerous sections in the structure. With these actions, the structure will be safe for vehicle loads, ensuring the safety of the people using it (Aziz, 2019).

2. Vehicles load on bridges

The engineers are using vehicles loads to design the bridges. To accomplish this, they typically use probable loads as a basis for their design.

There are different types of loading given by the vehicle type: single axle with single tires, single axle with dual tires, tandem axles with single tires, tandem axles with dual tires and tank track (Fig. 3), (Aziz, 2019).

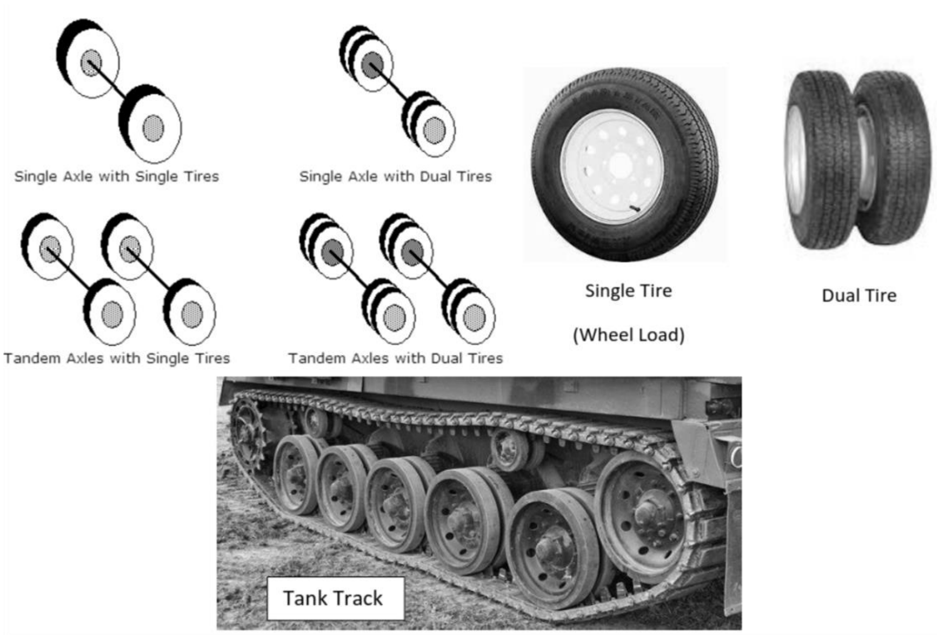

Fig. 3 – Constructive types of loading (Aziz, 2019).

AASHTO standard loading presents two types of trucks classified by weight and constructive form (Aziz, 2019; AASHTO, 1973):

1) Standard truck (H – loading), Fig. 4

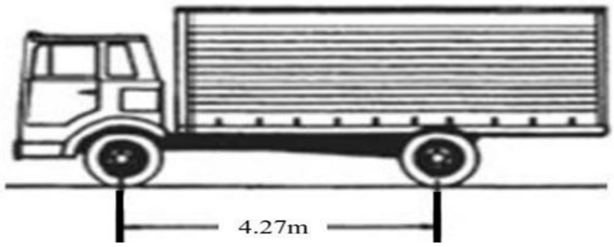

Fig. 4 – H loading type truck (Aziz, 2019; AASHTO, 1973).

Table 3
H loading type truck (Ali Hameed Aziz, 2019, AASHTO, 1973).

Designation	Front	Rear	Total Weight
H – 20	36 kN	144 kN	W=180 kN
H – 15	27 kN	108 kN	W=135 kN
H – 10	18 kN	72 kN	W=90 kN

2) Standard truck (HS – loading) – type truck-trailer, Fig. 5

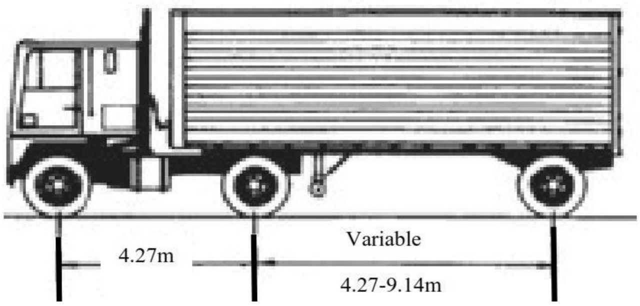

Fig. 5 – HS loading type truck (Aziz, 2019; AASHTO, 1973).

Table 4
HS loading type truck (Aziz, 2019; AASHTO, 1973)

Designation	Front	Intermediate	Rear	Total Weight
HS – 20	36 kN	144 kN	144 kN	W=324 kN
HS – 15	27 kN	108 kN	108 kN	W=243 kN

The equivalent uniform lane load has different values for each constructive type of truck (Fig. 6). To find values for this load, a uniform distributed load (W) is subjected to a shear force (V) which is placed anywhere on span to produce maximum effect. It is important to note that the lane width is 3.05 meters.

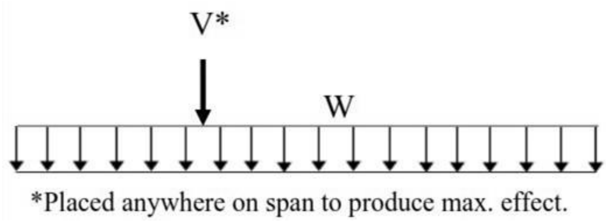

Fig. 6 – Equivalent uniform lane load (Aziz, 2019).

Truck	**Equivalent uniform lane load**		
	W kN/m-lane	*V (kN/lane)*	
		Moment	*Shear*
HS - 20	*9.3*	*80*	*116*
HS - 15	*7.0*	*60*	*87*
H - 20	*9.3*	*80*	*116*
H - 15	*7.0*	*60*	*87*
H - 10	*4.7*	*40*	*58*

Fig. 7 – Equivalent uniform lane load (Aziz, 2019).

H-10 and H-15 are used for design of roads that have low traffic volumes, H-20 and HS-15 are used to design expressways (Aziz, 2019), Fig. 7.

Longitudinal forces and impact factor given by vehicles are playing an important role on dynamic analysis of the bridges.

As we mentioned above regarding longitudinal forces, they are also called as braking force (Fig. 8). This force is transferring the load of vehicle from the truck wheels to the bridge deck (Aziz, 2019).

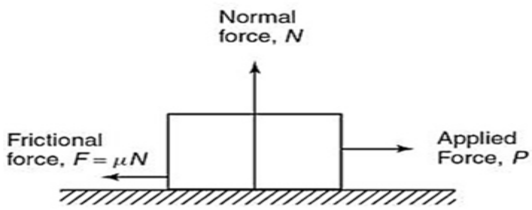

Fig. 8 – Force distribution (Aziz, 2019).

The force applied longitudinally is positioned at a height of 1.8 meters above the surface of the deck, and it is assumed that all lanes are traveling in the same direction. The impact of this force on the superstructure is deemed negligible. However, the substructure components (piers or abutments) are more significantly impacted (Aziz, 2019).

The impact factor is employed as a multiplier for particular structural elements. Basic principles of dynamics dictate that a load in motion produces greater stress than a static load (Fig. 9). The AASHTO standard specification defines the impact factor in the following manner (Aziz, 2019; Qassim and Ali, 2020):

$$I = [15.24/ (L+38.1)] \leq 30 \% \tag{9}$$

where: **I** is the impact factor and **L** represents length of span loaded to generate maximum stress.

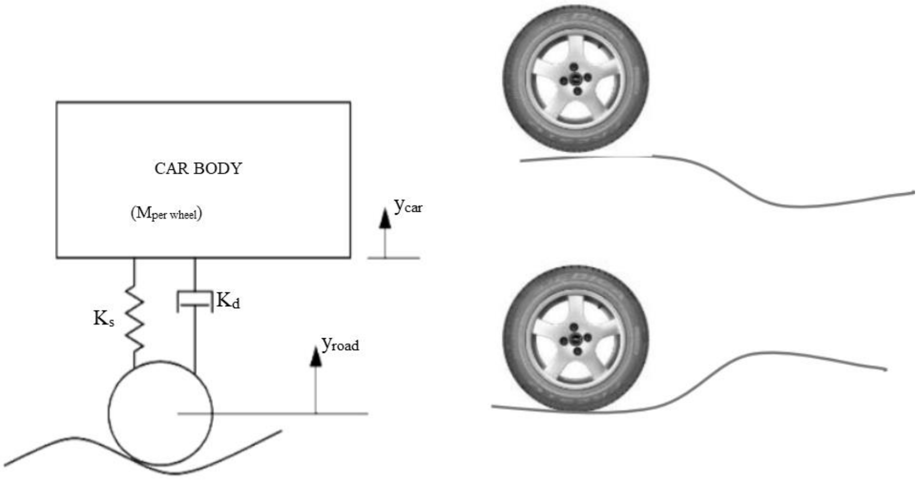

Fig. 9 – Impact factor explanation (Aziz, 2019).

The impact factor is not only intended to consider the dynamic response of the bridge to passing vehicles but also to account for the impact of a vehicle's vibration (vehicle motors) and impact on surface imperfections (such as potholes or uneven surfaces) on the deck. To account for the impact effect, the live load forces are multiplied by the impact factor (Aziz, 2019).

Based on the loading examples presented above we aim to perform finite element analysis on vehicle loads generated by trucks which act on the bridge structure, simulating different loading scenarios.

4. Conclusions

The goal of this study is to describe all types of loads that can appear in bridges. This description will help us in our future researches because we want to to perform different stress calculations on Octav Băncilă passage from Iași

(Romania). We will study how vehicles load are influencing the bridge characteristics.

To perform these simulations, we will use finite element methods generated with the help of ANSYS software. We choose this passage because it is highly circulated and is playing an important role for people safety.

Performing this analysis with vehicles loads, we can highlight dangerous sections of the bridge and take countermeasure. By doing this we will increase the reliability degree of the structure which will lead to an increased period of use for the bridge and also ensure safety for people that are using this passage.

REFERENCES

Aziz H., *Bridge Engineering*, Al-Mustensiryah University College of Engineering-Civil Engineering Department MSc. Course –Structures, 2019.

AASHTO (American Association of State Highway and Transportation Officials). Standard Specifications for Highway Bridges. 11th ed. Washington, DC: AASHTO, 1973.

Guojing Z., Yongjian L., Jiang L., Shiyong L., Jian Y., *Causes and statistical characterisitcs of bridge failures: A review*, Journal of Traffic and Transportation Engineering (English Edition), 2022.

Gang Z., Venkatesh K., Jincheng X., Shuanhai H., Wei H., *Behavior of prestressed concrete box bridge girders Under hydrocarbon fire condition*, Procedia Engineering, 210 (2017).

Icke P., Margheriti C., *The benefits and use of FE modelling in bridge assessment and design*, July 2010.

Qassim H., Ali M., DYNAMIC *Analysis of composite multi girders bridge using finite element method,* IOP Conf. Series: Materials Science and Engineering **928** (2020).

Scutaru M.C., *Contribuții la dezvoltarea metodologiei de monitorizare a podurilor – Studiu de caz privind aplicarea metodologiei de evaluare în concept dinamic la o structură nouă*, Doctoral Thesis, 2019.

Tirpathi M., Talawali L., *Static Analysis of Bridge Structure using Finite Element Analysis Software*, Mahendra Tirpathi Journal of Engineering Research and ApplicationISSN: 2248-9622, Vol. 8, Issue 6 (Part -I), June 2018.

Xue X., Wu M., Li Z. and Zhou P., *Numerical analysis of dead load shear force distribution in webs of multicell inclined web box-girder bridge*, Advances in Civil Engineering 2020, pp 1-10, 2020.

Zhang W., Murugesu V., Lian D., 24 Jan 2014, *Dynamic Analysis* from: Bridge Engineering Handbook, Seismic Design CRC Press Accessed on: 28 May 2023.

Zhan C., Xiedong Z., *Seismic response analysis of multispan bridge using FEM,* Tenth International Conference of Chinese Transportation Professionals (ICCTP) (2010).

Zhen S., Dionysius M. S., Yozo F., *Load-carrying capacity evaluation of girder bridge using moving vehicle,* Engineering Structures, 229 (2021).

ÎNCĂRCĂRI PE PODURI – PREZENTARE GENERALĂ

(Rezumat)

Podurile sunt întotdeauna supuse diferitelor tipuri de încărcări, care pot fi împărțite în trei mari categorii: încărcări verticale, încărcări transversale și încărcări longitudinale. Funcția principală a unui pod este de a avea o performanță bună sub încărcări grele reprezentate de mașini, camioane, trenuri și uneori tancuri. Scopul acestei lucrări este de a oferi o prezentare generală a tipurilor de încărcări care pot apărea pe poduri, cu accentul pus pe încărcările generate de vehicule. Această descriere va contribui la studiile noastre viitoare. Ne propunem să dezvoltăm cercetări ulterioare și să efectuăm diferite tipuri de calcule de stres pe pasajul Octav Băncilă din Iași (România). Analize de tip element finit vor fi realizate cu ajutorul încărcărilor generate de camioane care acționează asupra structurii podului, simulând diferite scenarii de încărcare. Pe baza valorilor calculelor de stres, vom evidenția secțiunile periculoase și vom lua măsuri pentru a îmbunătăți gradul de fiabilitate al podului analizat.