

## STRUCTURAL VEHICLE IMPACT LOADING

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**Abstract.** *In contemporary design, vehicle impact into the structures is paid great attention since they can be dominant, depending on the type of structure. The key issue in the vehicle impact analysis is the proper determination of intensity and way of action of dynamic forces on the structural element and its behavior after the imparted load. The Eurocodes, in the annexes provide recommendations for determination of force intensity depending on mass and velocity of the colliding vehicle. Equivalent static loads causing approximate effects on the structural elements are used as quite approximate and efficient methods. The paper comprises the analysis of deformation of columns having the same characteristics, exposed to impact loads via the equivalent static loads, depending on the stress state in columns, and a comparative analysis has been done.*

**Key words:** *vehicle impact, Eurocode 1, equivalent static loads, structure.*

### 1. INTRODUCTION

In the analysis of loads and impacts on the structural, very often is used the road vehicle impact load. The road vehicle impact load is exceptionally complex, so it must be considered individually for every building structure. Because of several different factors affecting the impact load and of the complex mathematical mole, in practice the dynamic load of vehicle impact is replaced by the static load multiplied by dynamic coefficients. Implementation of the finite element method facilitates performing of precise mathematical modeling and simulation of collision of vehicles with the structural elements. In the event of such modeling, as well as in the classic calculation, it is necessary to introduce certain assumptions or hypotheses, which primarily relate to material nonlinearity and imperfections, so the that the obtained results would be as close to the actual impacts as possible. Depending on the standards of individual states, the impact and analysis of vehicle impact load varies, so certain Standard will be presented further ahead. This paper present

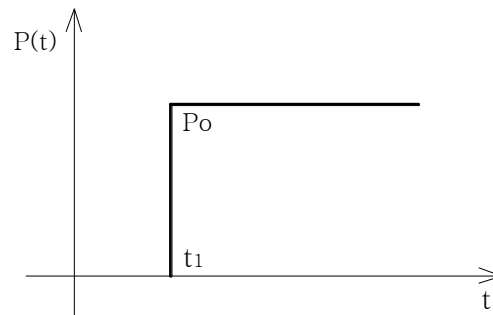
the basic principles of determination of impact load intensity depending on the velocity and mass of vehicles, and the comparative analysis of deformation of columns is provided.

## 2. THEORETICAL CONSIDERATIONS

Dynamic loads, as opposed to the static ones, are those which in time vary position, intensity or direction of action. The fundamental division of dynamic load is to: impact and vibration load. The dominant property of impact loads is the impact imparted to the structure, causing the acceleration of mass of the entire structure. The impact load can be periodic and aperiodic. [1].

The effect of abruptly applied load on the structures can be represented and defined via a variety of different mathematical functions. The abrupt loading occurs in the case when the force acting on the structure does not gradually increase from zero to its maximum value in a certain time interval, but is instantaneously applied. In technical sciences, the impact of abruptly applied load is most frequently defined according to the Heaviside step function  $H(t - t_1)$  [1] (Fig. 1).

$$H(t - t_1) = \begin{cases} 0 & t < t_1 \\ 1 & t \geq t_1 \end{cases}$$



**Fig. 1** Heaviside step function

The pulse belongs to impact loads. In the structural dynamic represents the product of force and time for which the force acts. The pulse action is most frequently represented with the Dirac delta function. In the contemporary structural design, a due attention is paid to specific forms of impact load, such as the heat shock, or abrupt exposure of the structure to extremely high temperatures, most frequently in case of explosion and of other hazardous impacts on structures.

## 3. VEHICLE IMPACT LOAD ACCORDING TO VARIOUS CODES

The effects of impact load of the bearing elements of structures are very different from those produced by static or quasi-static loads. The cause of this difference is the velocity

at impact and the energy imparted both to the structure and to the body colliding with the structure. For the proper study of the effects of impact from road vehicles, the knowledge of behavior of structural elements at the moment of impact into the structural element is of key importance, considering that the imparted energy affects the entire energy balance which must be absorbed by the certain element. The model used for the study of impact load must be as similar to the actual conditions as possible, so that is capable of emitting the precise amount of energy. It is important to emphasize that the most deformable body in this type of collision is the vehicle itself. The capacity of vehicles to absorb impact energy at low velocity is the topic of numerous studies in automotive industry and in medical research [2].

Most of the standards, substitute the impact effects by the equivalent impact load, which causes the same effects as the impact itself. These standards propose certain values of the impact load, or provide certain expressions for their calculation, but the problem is the considerable discrepancy of results, depending on the regulations [3].

Analysis: Eurocode EN1991-1-1:2002 [4]

In the Annex B, which is informative, and relates to the vehicle barriers and parapets for car parks, there is a recommendation for calculation of the horizontal force of vehicle impact. In the item B2 the horizontal characteristic force  $F$  (in kN) is precisely defined, normal and equally distributed at any length of **1,5m** car park barrier, which is required to receive the vehicle impact, and it is given by the expression:

$$F = \frac{0,5mv^2}{\delta_c + \delta_b} \quad (1)$$

where:  $m$  is the gross mass of the vehicle in (kg);  $v$  is the velocity of the vehicle (m/s), normal to the barrier;  $\delta_c$  – deformation of the vehicle (mm);  $\delta_b$  – deformation of the barrier (mm).

According to the Annex B, there are two basic design situations. The first is when the car park is designed on the basis of the gross mass of the vehicle which does not exceed 2500kg, when for determination of the force  $F$  the following values should be adopted:

$$m = 1500\text{kg}$$

$$v = 4,5\text{m/s}$$

$$\delta_c = 100\text{mm, unless better evidence is available.}$$

The second situation is when the car park is designed for the vehicles whose gross mass exceeds 2500kg, when for determination of the force  $F$  the following values should be adopted:

$$m = \text{actual mass of the vehicle for which the car park is designed (kg)}$$

$$v = 4,5\text{m/s}$$

$$\delta_c = 100\text{mm, unless better evidence is available.}$$

Analysis: Eurocode EN1991-7:2006 [5]

In this part of Eurocode, there is a different solution for calculation of vehicle impact load. In this part of Eurocode, there is another solution for calculation the intensity of vehicle impact into the bearing elements of the structure. The impact effects are defined

as "hard impact" , where the dissipation of energy is done mostly by the body colliding with the structure and as "soft impact" where the structure is designed so that it deforms in order to absorb the impact energy. For "hard impact", the value of equivalent static force can be obtained from the expression (1), or the alternative procedure can be the dynamic analysis represented by the simplified approximations. For "hard impact" analysis, it is supposed that the structural element is immovable and stiff, and the only the colliding body is deformed, and that it deforms in a linear fashion, during the impact phase. The maximum effect of the dynamic force of interaction is obtained according to the expression:

$$F = Vr\sqrt{km} \quad (2)$$

where:  $Vr$  is the object velocity at impact;  $k$  – equivalent elastic stiffness of the object (i.e. the ratio between force  $F$  and total deformation);  $m$  – is the mass of the colliding object.

The force due to impact may be considered as a rectangular pulse on the surface of the structure. In that case the duration of the pulse follows from:

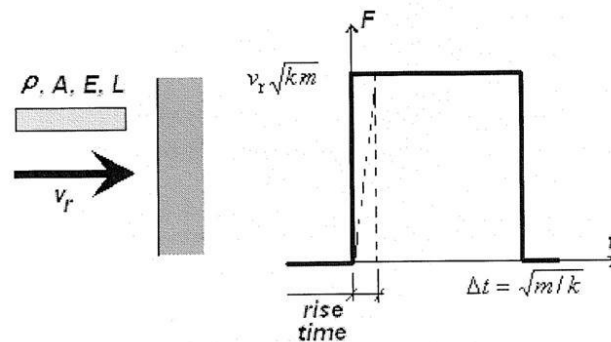
$$F\Delta t = mv \quad \text{or} \quad \Delta t = \sqrt{\frac{m}{k}} \quad (3)$$

When the colliding object is modeled as an equivalent impacting object of uniform cross-section (Figure 1.), the following should be used:

$$k = \frac{EA}{l} \quad (4)$$

$$m = \rho AL \quad (5)$$

where:  $L$  – is the length of the impacting object;  $A$  – is the cross sectional area;  $E$  is the modulus of elasticity;  $\rho$  is the mass density of the colliding object.



**Fig. 2** Impact model [4] ( $F$  – dynamic force of interaction)

Expression (1) provides the maximum value of the dynamic force on the external surface of the structural element. Inside the structure, this force may reach even higher

values due to the dynamic effect. The dynamic factor, based on the way of load application and the structural response may be in the range  $\phi_{dyn} = 1,0 \div 2,0$ . At any rate, it is recommendable to use direct dynamic analysis for determination and definition of the dynamic factor  $\phi_{dyn}$  with the already mentioned load values.

For "soft impact" if it is assumed that the structure is elastic and the colliding object rigid, the expressions given in (1) apply and should be used with  $k$  being the stiffness of the structure.

If the structure is designed to absorb the impact energy through plastic deformations, so that its ductility is sufficient to absorb the total kinetic energy  $1/2 mv^2$  of the colliding object. In the boundary case, at rigid-plastic response of the structure, the previous expression is satisfied by the conditions from the following expression

$$1/2 mv^2 \leq Fo y_o \quad (6)$$

where:  $F_o$  is the plastic strength of the structure, i.e. the limit value of the static force  $F$ ;  $y_o$  is its deformation capacity, i.e. the displacement of the point of impact that the structure can undergo.

Analogous considerations apply to structures or other barriers specifically designed to protect a structure from impacts.

Analysis: Spanish code of building, CTE) [6]

This code recommends the equivalent static load of 50kN for impact of vehicles having less weight of 30kN. At any rate, in this code, velocity, as a variable is not considered in particular and it is not possible to alter the input data such as the velocity and mass of the vehicles, to obtain a more precise results.

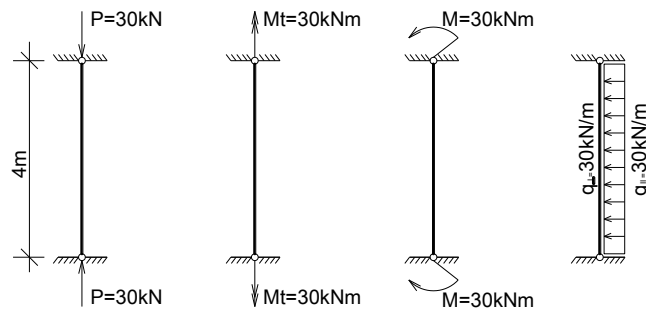
**Table 1** Values of equivalent static load according to different codes [3]

Source	Expression	Vehicle weight (kg)	Velocity at impact	Equivalent static force (kN)
CTE (Spanish code)	-----	3000	n/a	50
Eurocode 1 section 1.1 annex B	$F = \frac{0,5mv^2}{\delta_c + \delta_b}$	<2500 3000	16.2 20	150 308
Eurocode 1 Section 1.7	-----	n/a	<20	50-100
Eurocode 1 section 1.7 annex C	$F = Vr\sqrt{km}$	1500 3000 3000	10 20 10	59 166 83

#### 4. DEFORMATION OF CONCRET COLUMN DUE TO THE IMPACT LOAD DEPENDING ON THE STRESS STATE IN THE COLUMN

##### 4.1. Applied methodology

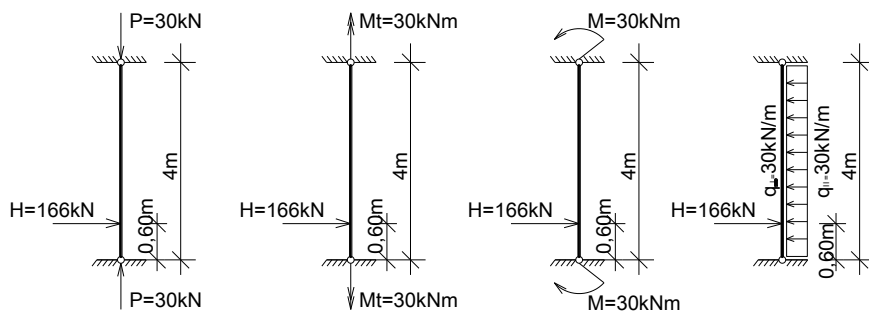
Based on the mentioned standards for calculation of the intensity and form of impact load, an analysis was conducted as well as comparison of the deformations of the concrete column loaded by the equivalent static force, according to the Eurocode 1, section 7, annex C. For modeling and impact analysis in the column, the software package "Radimpex Tower 6" [7] was used, that is, the finite element method [8]. Four columns, identical in terms of material and boundary conditions were individually modeled, and in each of them a different stress state, axial force, pure bending, torsion and bending were generated, (Figure 3). The goal of the research is determination of displacement of the impact force point, that is, drawing conclusion about the most favorable stress state on the occasion of vehicle collision with the column.



**Fig. 3** Different stress states of columns, on which the impact load is applied later

##### 4.2. Modeling of elements and equivalent static load

The column is modeled as a beam element with the characteristics of rectangular cross section 20/20cm, concrete class MB 30 (C25/30), 4m height. The element is hinged on both ends, and the desired stress state is cause in it, and later the equivalent static load from the vehicle impact (Figure 4). Equivalent static force was determined according to the Eurocode 1, section 7, annex C, for the vehicle up to 3000kg weight and maximum velocity at impact up to 20 km/h.



**Fig. 4** Equivalent static vehicle impact load

**Table 2** Displacement of the 20/20cm concrete column collision impact point

	Column 1 (axial force)	Column 2 (torsion)	Column 3 (pure bending)	column 4 (bending)
Displacement impact force points (mm)	13.27	13.27	20.64	2.54

## 5. CONCLUSION

Calculation of the vehicle impact, according to the standing standards, and using the contemporary modeling and simulation software differs from the traditional design methods. Depending on the Codes, there is large result scattering, that is, discrepancies in the force intensity of the same initial parameters (vehicle mass and velocity). By comparing the displacement of the force impact points, of the columns with various stress states, in this case, it can be concluded that the most favorable stress state in the column during vehicle impact is bending, since it deforms the column the least.

In all the events, during the analysis of vehicle impact effects, it is necessary to consider all the relevant factors affecting the intensity and direction of the load. Every case must be treated individually, regarding the specificity of the problem. In literature and standard, little attention was paid up to now, regarding the complexity of the issue, while in contemporary engineering, all incident loads are increasingly taken into consideration, as well as natural and human factor disasters – hazards and their impact on buildings and environment. Considering that such loads cannot be anticipated with certainty, their effects on the structures can be minimized, by proper design and construction.

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## **UDARNA OPTEREĆENJA VOZILA NA KONSTRUKCIJE**

*U savremenom projektovanju, udaru vozila na konstrukcije posvećuje se velika pažnja s obzirom da ona mogu biti dominantna u zavisnosti od vrste objekta. Ključno pitanje u analizi udara vozila, jeste pravilno određivanje veličine i načina delovanja dinamičke sile na konstruktivni element i njegovo ponašanje nakon nanešenog opterećenja. Evrocodovi u aneksima daju preporuke za određivanje intenziteta sile u zavisnosti od mase i brzine vozila koje vrši udar. Kao približne i dosta efikasne metode koriste se ekvivalentna statička opterećenja koja izazivaju približne uticaje na konstruktivne elemente. U radu je data analiza deformacije stubova istih karakteristika izloženih udarnim opterećenjem preko ekvivalentne statičke sile, u zavisnosti od stanja naprezanja u stubovima i urađena je uporedna analiza.*

*Ključne reči: udarna opterećenja vozila, Evrokod 1, ekvivalentna statička opterećenja, konstrukcija*