IMPACT LOAD IN PARKING STEEL COLUMN: CODE REVIEW AND NUMERICAL APPROACH

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Key words: Impact Load, Element Finite Modelling, Equivalent Static Load, Structural Dynamics.

Abstract. *European regulations, including the Eurocode 1, describe the dynamic forces originated by a vehicle impact on a structure by means of an equivalent static load based on the mass and the velocity of the vehicle that impacts on the column. The expressions used to determine this load and the values of the parameters involved in this problem are significantly different in each part of the Eurocode 1.*

In order to validate the expressions proposed by the Eurocode 1 for this equivalent static load, a numeric model of F.E.M. has been developed. This model analyzes the effect of a vehicle impact on a column of a conventional building parking.

A decisive factor in the obtained results is the dissipated energy during the impact. Some authors simulate the impact object by means of a rigid element but a real vehicle is very different than this object because it is designed to dissipate large amount of energy even at low velocity. The vehicle used to simulate the impact load was a Chevrolet pickup from the year 1994. The model of finite elements for the vehicle has been obtained of the USA National Crash Analysis Center database.

1   INTRODUCTION

The consequences of the impacts loads in structures are very different from those who produce the static or quasistatic loads. The cause of this difference is the velocity with the energy involved in the impact is transmitted and which must be absorbed both by the structure and by the body that impact. Therefore, in the study of the consequences of the impact is essential to know the behavior of the elements involved while the impact is happening, since the energy removed by them influences the entire energy balance and the energy that must absorb the element studied. Then, the model used to study an impact must be as similar to real problem that it is able to dissipate the correct amount of energy. Thus, it is important to notice that the most deformable body involved in this impact is the vehicle. The ability of vehicles to absorb energy in low velocity impacts has been the object of many studies, such as in the vehicles industry as in medicine research [1].

Most regulations assess the consequences of an impact by an equivalent impact load, which causes the same effects as the impact. These regulations sometimes suggest a particular value of the equivalent impact load or point the way to give it by some expressions, but the problem is the great disparity between them. Consequently there is an issue to be sorted out.

On this study we focus the impact problem on a steel column of a parking. The projectile is an ordinary vehicle. Also the column is subjected to static compressive loads originate from building above this column.

A finite element model has been made to obtain a static load which really represents the effects of an impact. The study of impacts by finite element analysis has been a subject of research in numerous papers. Most of them deal with the behaviour of concrete and steel barriers under high speed impacts [2, 3, 4]. ANSYS code [5] and LS-DYNA code [6] are usual computer tools based on F.E.M. employed to simulate impact loads, which have been widely checked in the papers mentioned above.

2   IMPACT LOADS IN CODES

2.1   Spanish code of building (CTE) [7]

The Spanish code of building establishes an equivalent static load of 50 kN for an impact due of a vehicle with less mass than 30 kN.

However, the velocity of the impact is not given in this standard and is not possible to change the input data such as the velocity and mass of the vehicle to obtain more accurate values, as the European Codes.

2.2   Eurocode 1. Part 1-1 [8]

Annex B, which is only informative, indicates that the force necessary to take the impact of a vehicle can be calculated through:

$$F = 0,5 \cdot m \cdot v^2 / (\delta_c + \delta_b) \qquad (1)$$

Where: m is the gross mass of the vehicle (in kg), v is the velocity of the vehicle (in m/s) normal to the barrier, δ_c is the deformation of the vehicle (in mm) and δ_b is the deformation of the barrier (in mm)

Also, for car parks designed for vehicles which do not exceed 2500 kg, this code specify the values of the input parameters to obtain F, and with these values F results 150 kN, assuming a rigid barrier. For vehicles with more than 2500 kg the same expression with the

real mass of the vehicle can be used. Then, in this case, and for a velocity of 20 km/h, the equivalent static load would be of 308 kN.

This equivalent static load is much higher than the load suggested in the Spanish code for an impact with the same characteristics.

2.3 Eurocode 1. Part 1-7 [9]

On this part of Eurocode we find another solution for impact loading over structures. All the rest of Eurocode's documents point to this part in relation of impact loads. On this field it is included car parking, so its application to this work is direct.

The impact studied is a "hard impact", as defined in this rule; for this kind of impact and velocity lower than 20 km/h, the equivalent static load suggested is between 50 and 100 kN, being recommended the lower value. This is the value that CTE has adopted in its articles, so it is possible that the Spanish rule was based on European regulations.

On the other hand, on Annex C of this part of the Eurocode, which is only informative, it appears another procedure to make a dynamic calculation of the problem. For a hard impact and understanding the impacting object deformation as lineal, the following expressions are given:

$$F = v_r \cdot \sqrt{k \cdot m} \qquad (2)$$

Where: v_r is the object velocity at impact, k is the equivalent elastic stiffness of the object (i.e. the ratio between force F and total deformation) and m is the mass of the colliding object.

On the other hand, the code includes notional probabilistic information for the basic variables, and with these values, the equivalent static load would be of 60 kN. But if we use these expressions with a mass of 3000 kg and velocities of 10 and 20 km/h, we obtain 80 kN and 160 kN, respectively.

In any case, these values, on table 1, are higher than those specified in the Spanish code, which agrees with this part of the Eurocode but with a colliding object with half mass that the Spanish code. In any case, there is a big scatter on results, even for the same input parameters.

SOURCE	Expression	Vehicle mass (kg)	Impact velocity (km/h)	Equivalent static load (kN)
CTE	--------	3000	No shown	50
EUROCÓDE 1 PART 1.1 ANNEX B	$F = 0,5 \cdot m \cdot v^2 /(\delta_c + \delta_b)$	<2500	16.2	150
		3000	20	308
EUROCÓDE 1 PART 1.7	--------	No shown	<20	50-100
EUROCÓDE 1 PART 1.7 ANNEX C	$F = v_r \cdot \sqrt{k \cdot m}$	1500	10	59
		3000	20	166
		3000	10	83

Table1: Values of equivalent static load obtained by different codes.

1. METODOLOGY USED

The study has been focused on the impact of a vehicle with a metallic column with section type HEB-450 and Fe 430 steel. This column is part of the basement of a 6 floors building located in a parking area.

The determination of the equivalent static load is achieved through the comparison between the results obtained in static and dynamic simulations. The parameter of comparison is the maximum displacement in the axis of the column in the direction of the impact. In these simulations a static load has been applied. The area in which this load is applied is a rectangular area of 0.25 m in height and the complete width of the element; the centre of this area is located at a height of 0.60 m from the base of the column (Fig. 1 (A)). Moreover, both in the static and in the dynamic simulation, the load is being applied in the perpendicular direction to the axis of lower inertia of the section (Fig. 1 (B)), for being the least favourable.

(A)

(B)

Displacement
calculated
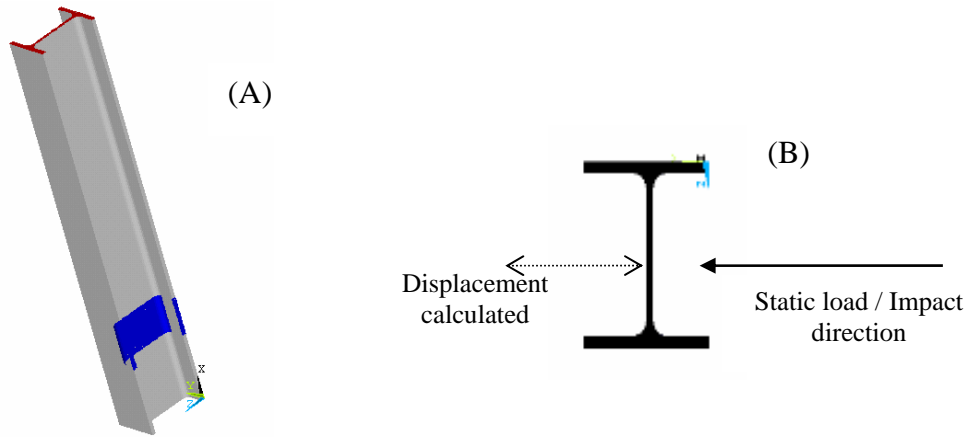
Static load / Impact
direction

Fig. 1: Area of application of the load (A) and direction of applied load and displacement calculated (B)

For dynamic simulations it has inferred the impact of a vehicle against the column. This represents a originality compared to the work done in this area, where the projectile used was rigid [10, 11, 12]. This rigid projectile does not take into account the characteristics of shock absorber of the projectile which influence on the exchange of energy of the impact and therefore on the consequences of the impact on the column.

2. NUMERICAL MODELLING: STATIC AND DYNAMIC

The static model for the simulations has been done in ANSYS code, and for dynamic simulations has been used the LSDYNA code.

2.4 Elements used

For static simulations the column was modelled with SOLID45 element. This element has hexahedral form and is defined by 8 nodes with three degrees of freedom at each node. It has plasticity, swelling, stress stiffening, large deflection and large strain capabilities. For dynamic simulations it was used SOLID element, which also has hexahedral form.

The size of the elements in both cases is 1.5 x1.5x0.95 cm and the entire model of the column has a total of 54226 elements and 70895 nodes.

2.5 Materials and constitutive models

In all the simulations a bilinear isotropic hardening model were used, with the values: elastic modulus: 210 GPa, Poisson ratio: 0.3, density: 7850 kg/m^3, yield stress: 275 MPa, tangent modulus: 0. To evaluate plasticity areas Von Mises yield criterion was employed.

2.6 Applied loads

In all the simulations a load, such as supporting a column located in the basement of a 6 floor building, has been applied at the head of the column. This load consists of an axial load of 3436 kN and a bending load of 4.58 kN·m.

These loads have been combined with a second load located 0.60 m from the base of the column in the case of static simulations and with the dynamic load imposed by the impact of the vehicle in case of dynamic simulations. In both cases this additional load was applied in the perpendicular direction to the axis with lower inertia in this section.

2.7 Boundary conditions

The column is completely base fixed and its head displacement is only restricted in its horizontal plane.

2.8 Projectile used

In order to reflect the energy exchange that takes place during the impact of a vehicle on a column, we used a finite element model for the vehicle that accurately describes both the geometry characteristics such as resistance to all elements in a real vehicle. This model has been created by the NCAC (National Crash Analysis Center), the FHWA (Federal Highway Administration) and NHTSA (National Highway Traffic Safety Administration) in coordination with The George Washington University (Virginia) [14]. The complete model consists of 66050 nodes and 57850 elements. To validate this model, George Washington University has made the comparison between the results obtained from a simulation test NCAC [15] and the actual vehicle test conducted by the NCAC in the same conditions. The results corroborate the accuracy of the model with the real car [14].

2.9 Simulations

Static and dynamic simulations with different loads and objectives pointed in Table 2 have been carried out.

Type	Load	Objective
Static	Originated from building	Validating column model
	Originated from building + static load with values: 25, 30, 35, 50, 110, 120 and 130 (kN)	Obtaining maximum displacement of column and comparison with dynamic simulations
Dynamic	Originated from building + Impact by vehicle with velocity of 10 km/h and mass of 1800 kg	Obtaining maximum displacement of column and comparison with static simulations
	Originated from building + Impact by vehicle with velocity of 10 km/h and mass of 3000 kg	
	Originated from building + Impact by vehicle with velocity of 20 km/h and mass of 1800 kg	
	Originated from building + Impact by vehicle with velocity of 20 km/h and mass of 3000 kg	

Table 2: Simulations done, applied loads and objectives for each simulation

3. NUMERICAL RESULTS

Simulations with the static load transmitted through the building allowed to verify the accuracy of the model of the column, through taking into consideration the known relationships between the applied load, effort and expected movements in linear behaviour.

On the other hand, in relation with the dynamic simulations, it is noted that the general condition of the vehicle after impact shows plastic deformation in all cases (Fig. 2.A). These plastic deformations are visibly higher in the simulations with speed of 20 km/h with respect to 10 km/h and there is no significant difference between the simulations carried out with different masses.
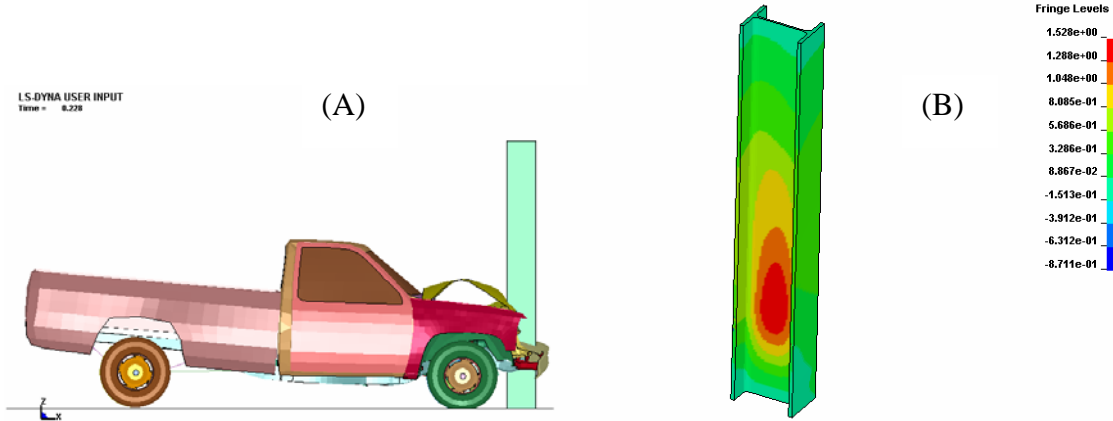

Fig. 2: Obtained results with a velocity of 20 km/h and a mass of 3000 kg: Plastic deformation in the car after the crash (A) and displacement (mm) in the column in the direction of the impact (B),

The effect of the impact has not been relevant in the movements observed in the direction of de axis of the column and in the perpendicular direction to the impact. Only minor deviations have been noted in the case of the simulations with a speed of 20 km/h.

In order to find out the maximum displacement of the column in the direction of the impact (Fig. 2.B), several random points were taken at different heights of the column. Also, these points have been taken in the axis of the pillar with the objective of avoiding distortions in the measurements due to the Poisson effect and local effects in the area of application of load. The displacements obtained at these points as a function of time for each of the simulations carried out are shown in Figure 3.

The equivalent loads obtained from the static model with the maximum movements imposed by the dynamic simulations are shown in Table 3.

Simulation nº	Velocity (km/h)	Mass (kg)	Maximum displacement (mm)	Equivalent static load (kN)
1	10	1800	0.35	29
2	10	3000	0.4	32
3	20	1800	1.6	130
4	20	3000	1.4	114

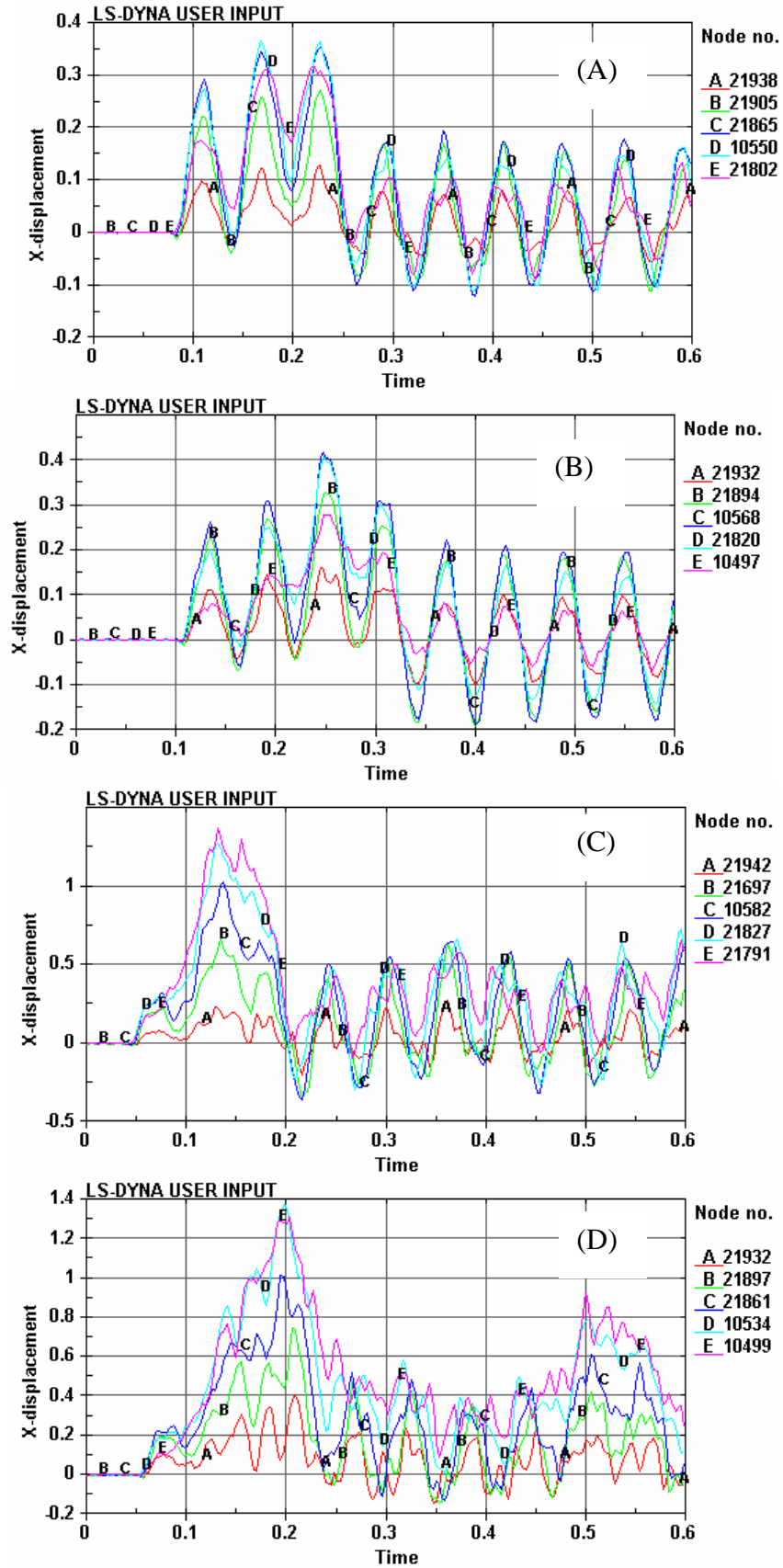Table 3: Maximum displacement and equivalent static load for each dynamic simulation

Fig. 3: Displacement in the direction of the impact (mm) of some selected nodes from the axis depending on time (s): (A) and (B) for a speed of 10 km/h and mass of 1800 and 3000 kg; (C) and (D) for a speed of 20 km/h and mass of 1800 y 3000 kg.

4. CONCLUSIONS

This case study shows a research on the impact load caused by vehicles on parking columns through dynamic analysis developed with programming methods based on the finite element method. Through this analysis the maximum displacement that produces the impact on the columns has been determined. Also by comparing with static simulations, the equivalent static load that produces the same displacement has been established for each case. Consequently and by observing the results obtained we can state that:

The static load equivalent to an impact depends intensely on the speed of the vehicle which hits it; this is why it is not possible to give a value of this load without taking into account the speed of the impact to that which is equivalent to.

The energy dissipated by the vehicle is essential in the study of the equivalent static load, meaning that the type of vehicle involved in the impact should be taken into account. This study was conducted with an ordinary passenger car, however there may be impacts on parking with other vehicles, and small machinery maintenance whose buffer features have nothing to do with an ordinary car.

The load suggested by the CTE matches with the one recommended by the Eurocode 1 on part 1.7 for a "hard" impact with a speed up to 20 km/h. However, the application of the expressions that this rule offers later on leads to loads higher than those indicated in the CTE to any speed and are on the order of 80 kN and 160 kN for speeds of 10 km/h 20 km/h respectively.

Finally, and for the studied metal column, the equivalent static load that CTE suggests is safe at the speed of 10 km/h; however for a speed of 20 km/h is insufficient, being calculated in this study on 130 kN. This is roughly the load that is obtained with the expressions given by the Eurocode 1 part 1.7, annex C, for the parameters used in this study. Therefore, the values that best approximate the simulations carried out are those that are obtained using these expressions.

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