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NUMERICAL MODELING OF THE IMPACT PROBLEM USING OPEN SOURCE SOFTWARE

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ABSTRACT

Numerical modeling of impact problem using elastic and elastoplastic constitutive models and open source software is presented. The first case is an elastoplastic model for the analysis of a cylindrical aluminum element that impacts on a rigid surface; the second case, is an impact model of a body on the center of simply supported aluminum beam introducing elastic and elastoplastic constitutive models. This work is originated from the need to explore some possibilities of impact phenomenon modeling. The main contributions were: establish the importance of the constitutive models in modeling the impact phenomenon, accessing to explicit dynamic models of impact with Open Source Software like “Impact” Finite Element Program and explore possibilities of parallel computing and multi-platform as this software is developed in Java and offers possibilities for using several processors in parallel. Some results were compared with theoretical solutions. It´s noted that variation between the behavior of the elastic and elastoplastic material models in the instant of impact is significant as well as the advantage of using several processors in modeling the phenomenon due to small size of time steps that normally generate a high volume of iterations and a great computational cost of the models.

Keywords: impact, explicit dynamic, numerical modeling, open source software.

1. INTRODUCTION

Impact program is a free alternative to the advanced commercial Finite Element codes available today. It's a Finite Element Code written in Java, based on an Explicit Time stepping algorithm to simulate dynamic phenomena that usually involving large deformations. Is an important application considering there are quite few explicit codes but implicit finite element codes are quite common.

An impact analysis is especially useful to predict behavior a structure under impacts or short-duration high-pressure loadings. Engineers can improve its design with using explicit dynamics (Uri, 1995). Some complex problems require advanced analysis tools to accurately predict the effect of design considerations on structure and gaining insight into such complex reality is especially important when it is too expensive or impossible to perform physical testing.

The impact study under the hypothesis of deformable solid, using elastic and elastoplastic constitutive models is a topic of wide interest in understanding the behavior of structural elements subjected to varying loads in very short time instants (Belytchko, 1984). In the practice, is possible modeling these phenomena with simplifications of the theory of elasticity analytical way or using the explicit dynamic models. However, in real life, impacts generate internal stresses exceeding the elastic limit of the material and therefore it is necessary to use elastoplastic constitutive models to provide a prediction close to the real when considering the possible errors that may exist in the parameters and the calculation process (Cook, 2002).

Numerical modeling of impact problem using elastic and elastoplastic constitutive models and open source software is presented. The first case is an elastoplastic model for the analysis of a cylindrical aluminum element that impacts on a rigid surface; the second case, is an impact model of a body on the center of simply supported aluminum beam introducing elastic and elastoplastic constitutive models. This work is originated from the need to explore some possibilities of impact phenomenon modeling. The main contributions were: establish the importance of the constitutive models in modeling the impact phenomenon, accessing to explicit dynamic models of impact with Open Source Software like Impact Finite Element Program and explore possibilities of parallel computing and multi-platform as this software is developed in Java and offers possibilities for using several processors in parallel. Some results were compared with theoretical solutions. It´s noted that variation between the behavior of the elastic and elastoplastic material models in the instant of impact is significant as well as the advantage of using several processors in modeling the phenomenon due to small size of time steps that normally generate a high volume of iterations and a great computational cost of the models.

The paper shows the influence of constitutive models on the impact phenomenon. Impact software is a useful tool to be used in teaching and research work, the correspondence between results obtained from modeling process and theorical solution is the evidence. Choosing a constitutive model requires be careful and need to know very well the assumptions used by the tool. Note that the experimental results show there is considerable distance between the model and the actual measurement and this depends of hypothesis considered. Impact software include parallel computing using several processes operating parallel, in this case we use two processors. The small size of time steps in explicit dynamic problems generates a high volume of iterations and a great computational cost.

The Impact software has advantage of using several processors in modeling.

2. METHODOLOGY

Since Impact program is modular, modeling process is divided into separate stages which are: pre-process, process, post-process and graph. Pre-process is the starting point and is used for: creating geometry, creation of finite element model, setting of loads and boundary conditions, setting of solver parameter values such as time step and exporting files for the solver. The process is where the calculation is made; the starting point is the file which is saved from the pre-processor. Post-process is used to view the results from the solver; these are saved in a file ending with *.flavia.res and it consists of multiple time steps.

2.1. Impact cases

2.1.1 Impact of an aluminum bar in a rigid edge

The case of a cylindrical aluminum bar that hits a rigid wall at a speed V is analyzed (Figure-1). We can use an elastoplastic constitutive model in order to find the length of the deformed bar. This case corresponds to C8 Ansys problem and is useful to make a benchmarking [7].

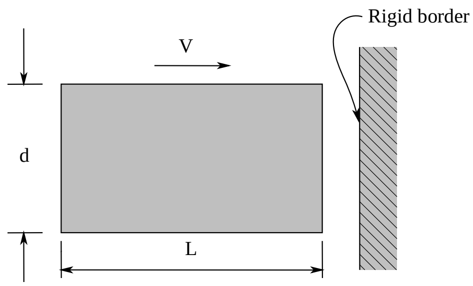

Figure-1. Cylinder impact problem.

The material properties, geometric properties and the impact speed of the aluminum bar are shown in Table-1.

Table-1. Problem data case # 1.

Parameter	Notation	Value	Units
Elastic modulus	E	70	GPa
Tangent modulus	ET	100	MPa
Yield strength	σ_{yp}	420	MPa
Poisson ratio	ν	0.3	---
Density	ρ	2700	kg/m3
Length	L	2,347	Cm
Diameter	d	0,762	Cm
Impact speed	V	478	m/s

From mechanics of materials we can propose the conservation equation (1) assuming an energy balance at the instant of impact, knowing that the kinetic energy of the moving mass is V0 and all the energy is transformed into strain energy of the bar.

$$\frac{MV^2}{2} = \frac{EA\delta^2}{2L}, \qquad (1)$$

Where, δ is the maximum deflection at the end of the bar, A is the cross section area, V is the impact velocity and L is the length of the bar. Thus:

$$\delta = \sqrt{\frac{MV^2L}{EA}}, \qquad (2)$$

If ρ=M/V, where V is the bar volume calculated as V=AL, then M=ρAL. Thus:

$$\delta_{th} = \sqrt{\frac{\rho V^2 L^2}{E}}, \qquad (3)$$

is the theorist displacement for the elastic model.

2.1.2. Impact of a mass on a beam

In this case we take an arbitrary point (x, y) in the coordinate system XY and we seek a relationship with the coordinates of the point in a system rotated an angle θ.

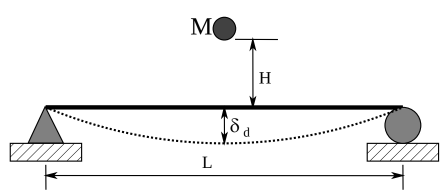

Figure-2. Beam impact problem.

Table-2 shows the properties of material, the geometrical properties, and the impact velocity of mass M over the aluminum bar.

Table-2. Problem data case # 2.

Parameter	Notation	Value	Units
Elastic modulus	E	70	GPa
Tangent modulus	ET	100	MPa
Yield strength	σ_{yp}	420	MPa
Poisson ratio	ν	0.3	---
Beam density	ρ	2700	kg/m3
Length	L	1.0	m
Beam width	b	0,02	m
Beam depth	h	0,0171 m	m
Drop height	H	1,0	m

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From the mechanics of materials static deflection in the midpoint of the beam can be calculated as:

$$\delta_{st} = \frac{MgL^3}{48EI}, \tag{4}$$

Where, M is the mass which impacts the beam, g is the value of gravity acceleration, L is the beam length, E is the elastic modulus of the material, I is the inertia centroidal moment of the cross section, δst is the static deflection in the midpoint of the beam. Moreover, deflection for impact can be calculated as:

$$\delta_d = k_d \delta_{st} \tag{5}$$

Where, δ_d is the maximum deflection due to impact, k_d is the dynamic amplification factor includes the offset by the dynamic effects of impact. The coefficient *kd* can be calculated by introducing a β factor as a relation between body mass *M* and the mass of beam *m*, thus:

$$k_d = 1 + \sqrt{1 + \frac{2H}{\delta_{st}(1 + \alpha * \beta)}}, \tag{6}$$

where, H is the drop height of the body, β=M/m.

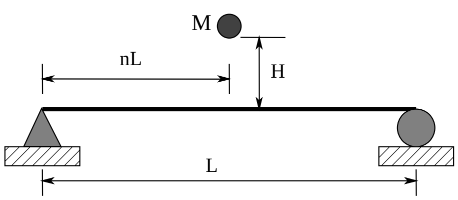

Figure-3. Explicit dynamic scheme.

According to Figure-3, coefficient α can be calculated as:

$$\alpha = \frac{2 + 4n - n^2 - 6n^3 + 3n^4}{105n^2(1-n)^2}. \tag{7}$$

3. RESULTS AND DISCUSSIONS

Figures 4, 5, 6, show details of the first model using the Impact Open Software also the displacements results on the bar end with isocontours.

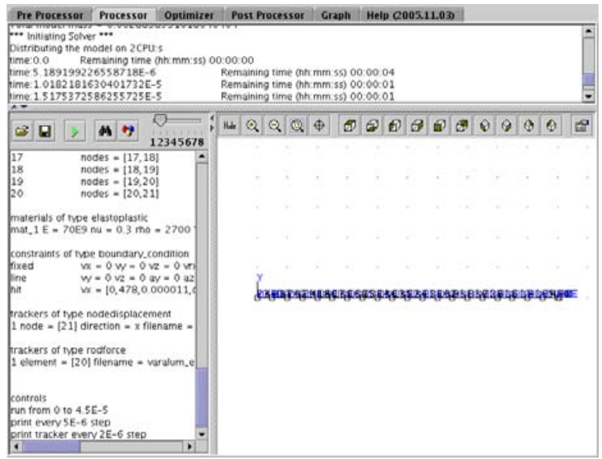

Figure-4. Some details of numeric model.

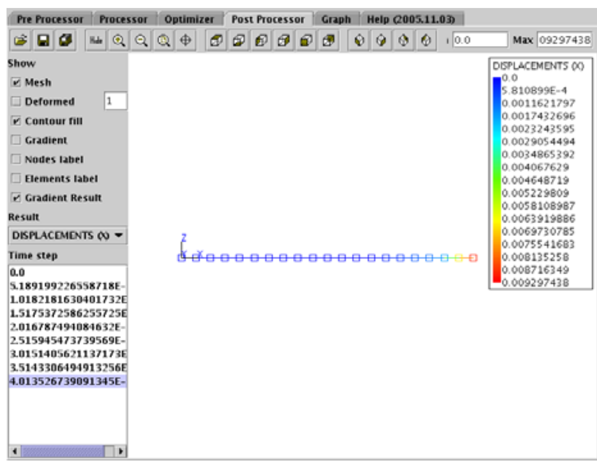

Figure-5. Displacement in the last time step.

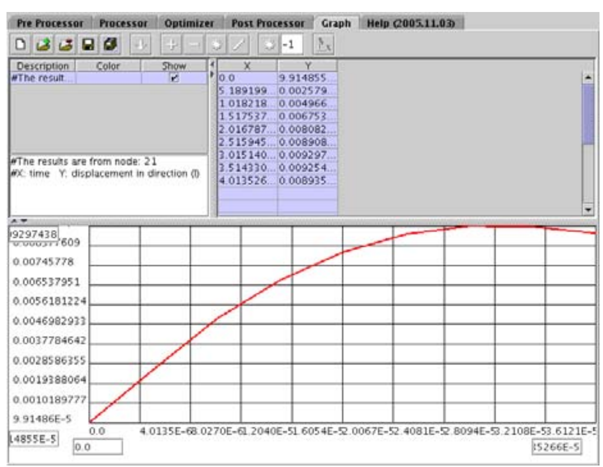

Figure-6. Displacement vs. impact time.

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Table-3. Comparison of results case # 1.

Lf (cm)	**Value**	**Variation** (%)
Experimental	1.319	---
Theorist	2.127	61.3
Impact	1.413	7.10
Ansys	1.407	6.70

From the problem data in Table-1 and equation (3) we can calculate analytically the maximum deflection at the bar end for an elastic constitutive model, getting as a result δ=2,203 mm. Table-3 presents comparisons of the final length *Lf* obtained from the elastoplastic model using Impact, the analytical solution and elastoplastic model using Ansys (benchmarking), all of them compared to experimental evidence. Ansys model was made with finite elements PLANE82. Impact software includes parallel computing using several processes operating in parallel. In this case we use two processors (see Figure-4). The small size of time steps generates a high volume of iterations and a great computational cost. Impact has advantage of using several processors in modeling.

The theorist final length from the elastic model has a high variation because plastic deformations are present. Impact results are very satisfying inasmuch as the mesh used is thick, also, the bar finite element used is simple compared to Ansys finite element that has a higher order of approximation and the possibility of modeling the 2D problem more in detail using axisymmetric properties.

Meanwhile, Figures 7, 8 and 9 show details of models and the beam's displacements for the second case with isocontours. Two models were developed; one of them to represent the elastic model (Figure-7) and the other one (Figure-8) to represent elastoplastic model.

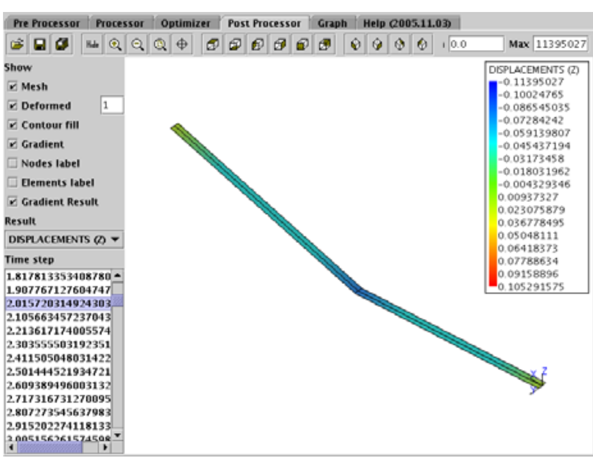

Figure-7. Displacement-last time step. Elastic model.

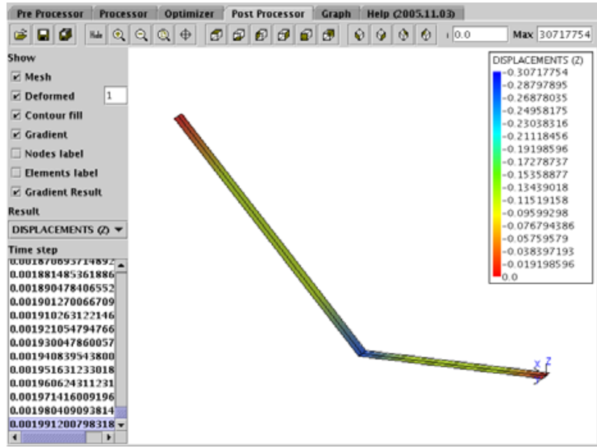

Figure-8. Displacement-last time step. Elastoplastic model.

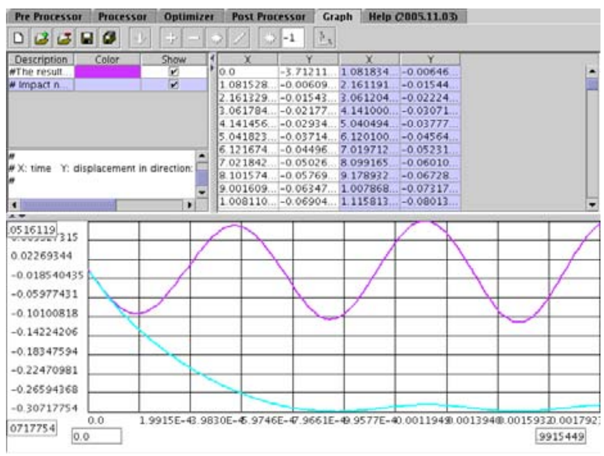

Figure-9. Beam's midpoint displacement vs. time.

From the problem data of Table-2 and equations 4 to 7 for an elastic constitutive model we can calculate beam's midpoint deflection [δd] analytically.

If gravity acceleration g=10 N, for n=½ so, α≈0.5, β=0.0616, δ_{st}=0.0054 m, kd=19.99, δd=0.1079 m. Table-4 presents comparisons between the maximum deflection obtained from the models and the theoretical solution.

Table-4. Comparison of results case # 2.

δ_d [cm]	**Value**
Theorist	9.56
Impact-Elastic	10.79
Impact-Elastoplastic	32.22

The results of the elastic model and the theoretical solution are consistent. The elastoplastic deflection is approximately three times the elastic deflection then the constitutive model has a strong influence over behaviour. In fact, we can see that the deflection curve of the elastic model is oscillatory while the deflection of the elastoplastic model is stable in time.

4. CONCLUSIONS

The paper shows the influence of constitutive models on the impact phenomenon. Impact software is a useful tool to be used in teaching and research work, the correspondence between results obtained from modeling process and theoretical solution is the evidence.

Choosing a constitutive model requires be careful and need to know very well the assumptions used by the tool. Note that the experimental results show there is considerable distance between the model and the actual measurement and this depends of hypothesis considered.

Impact Open Source Software includes parallel computing using several processes operating in parallel; in this work we use two processors. The small size of time steps in explicit dynamic problems generates a high volume of iterations and a great computational cost. The Impact software has advantage of using several processors in modeling.

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