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Theoretical and Numerical Study and Comparison of the Inertia Effects on the Collapse Behavior of Expanded metal tube Absorber with Single and Double Cell under Impact Loading

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ABSTRACT: The present study provides the theoretical and numerical comparison and study of the dynamic behavior of a four-rod and four-elastic-plastic joint model under the inertia effects in both single and double cell modes. The theoretical study was carried out by solving nonlinear equations in MATLAB with dynamic equations of motion. Numerical analysis was also carried out with ABAQUS. The objective of this study is to derive the equation of energy absorption in terms of the inertia parameter to the expanded metal tube structure under impact loading and also to study the dynamic behavior of effective parameters and collapse mechanism of the structure in both single and double cell modes. Finally, the analysis of the effect of double cell absorber was carried out for the values of effective parameters in dynamic response. The results show that the collapse of the absorber will be symmetric in two directions.

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1- Introduction

English and Calladine [1] identified two generic types of structures which plastically deform to absorb energy. The theoretical model used in the reference list entry takes into account the transverse inertia effect which appears to be in conflict with the plastic model of the joint which was adopted to evaluate the strain rate effect on the material response. Therefore, the inertia effects addressed in the present study cannot be integrated with that model. Tam and Calladine [2] performed an empirical study of a similar issue to the present research. The experiments were performed by a drop-hammer machine on a large number of specimens with the same basic geometry of two different selected materials. However, the elastic effects in the structural models were not addressed and a clear understanding of the role of dynamic yield stress was not reached.

The objective of the present study is to investigate and compare the theoretical and numerical values of an integrated structure which is analyzed as a single and double cell model, in which the elastic-plastic and inertial effects on this energy absorber are studied as an integrated dynamic analysis.

2- Theoretical Method

In order for the effects of inertia to be studied, it is assumed that each rod has a mass of $2m^*$, which is concentrated at its two ends. Therefore, there is a mass of $2m^*$ in each of the four corners of this model (i.e., A, B, C and D points in Fig. 1). Moreover, the striker with a mass of G moves at an initial pre-impact mode velocity of V_0, and remains attached to the top of the structural model from the moment of impact until the end of the response. Fig. 1 shows a schema of a single cell absorber as well as the effective parameters defined.

2- 1- Dynamic equations of motion

The total kinetic energy of the system is calculated by the following equation as the time derivative of the coordinates x and y:

$$K = \frac{1}{2}(G + 3m^*)(\frac{dY}{dt})^2 + 2m^*(\frac{dx}{dt})^2 \tag{1}$$

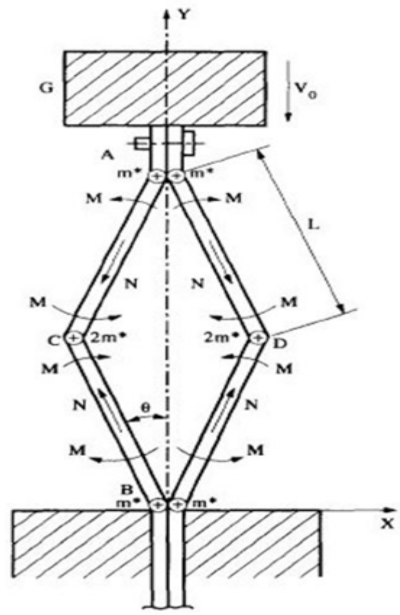

Fig. 1. Schema of single cell model [2]

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Finally, a system of ordinary differential equations is obtained in the form of Eq.(2) after the derivatives are implemented, separated and simplified in terms of generalized coordinates in the second-order Lagrange's equation.

$$\dot{\zeta} = n\sin(\theta) - 2m'\cos(\theta)/(1-\varepsilon)$$
$$\dot{\eta} = [4m'\sin(\theta)/(1-\varepsilon) + 2n\cos(\theta)]/\gamma + 3$$
$$\dot{\varepsilon} = -\left(\zeta\sin(\theta) + \frac{\eta\cos(\theta)}{2}\right) \quad (2)$$
$$\dot{\theta} = (\zeta\cos(\theta) - \eta\sin(\theta)/2)/(1-\varepsilon)$$

The first and second unknowns of the above system are respectively the dimensionless horizontal and vertical velocities. Finally, the derived equation system (2) was solved by the Runge Kutta iterative algorithm at specific initial conditions using MATLAB.

2- 2- Theoretical results

According to Fig. 2, which shows the mechanism of single cell absorber impact force variations during its deformation history, the dynamic response of the structure under impact load occurs in four phases.

2- 3- Numerical

The second cell is exactly the same as the first cell in terms of all the specifications, including the geometric and physical characteristics, and material. In the theory of double cell absorber, at first, the first cell opened to the defined stop angle of $\theta_s = 6.4°$ and to get closer to the actual process and reduce the error of assumptions used, the collapse of the second cell starts from the plastic mode instead of being the elastic mode.

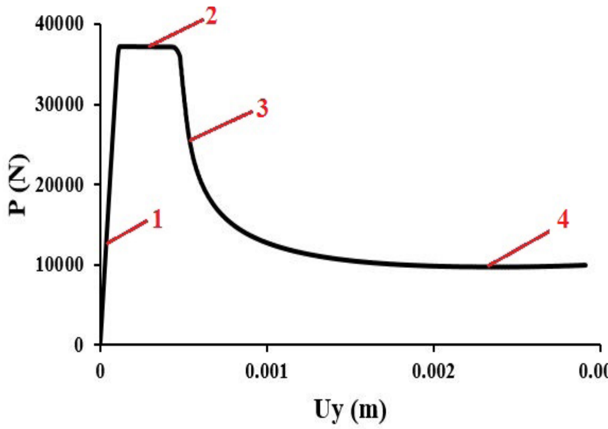

Fig. 2. Force-displacement diagram of single cell absorber U_y Vertical displacement

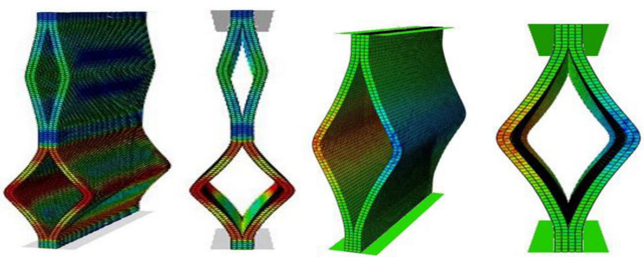

Fig. 3. Schematic diagram of single and double cell absorber collapse in both front and isometric views at the end of time intervals

Table 1. Comparison of the theoretical and numerical results of single and double cell absorbers

Single cell	U_y mm	U_x mm	E_T J	P_a N	P_{max} N
Theoretical	2.91	6.34	34.12	9588	37412
Numerical	2.76	6.24	35.31	7896	38352
Error Percent	5.2	1.6	3.38	17.6	2.45
Double cell					
Theoretical	1.93	5.52	48.1	8460	37036
Numerical	2.14	5.45	42.3	8178	37976
Error Percent	9.82	1.3	12	3.3	2.48

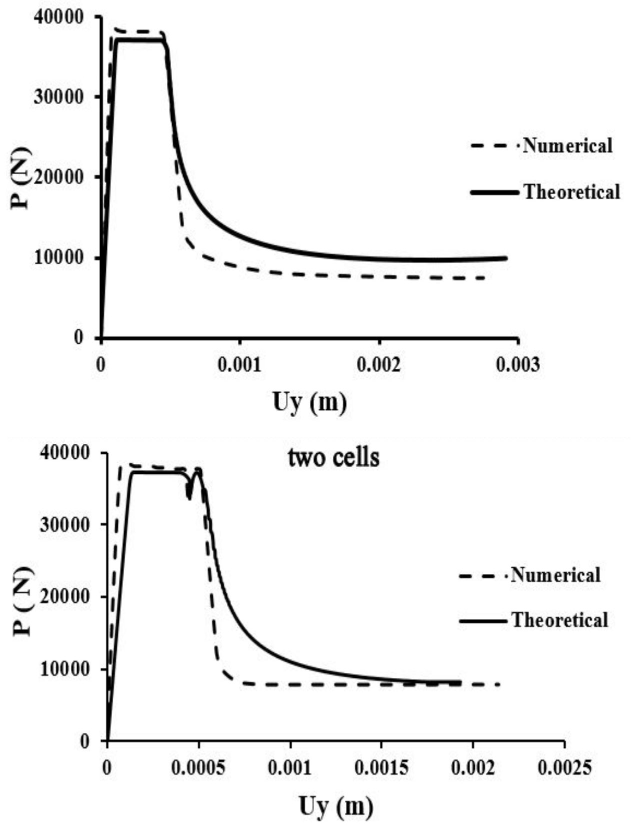

Fig. 4. Theoretical and numerical comparison of the force-displacement diagrams of single and double cell absorbers

3- Numberical Method

Fig. 3 shows the schema of single and double cell absorbers with the finite element model considered in both front view and isometric view at the end of the analysis time (t = 1/5 ms).

4- Comparison of Theoretical and Numerical Results

Fig. 4 and Table 1 simultaneously compare the results of both methods as well as the double cell absorber effects. The double cell absorber (force-displacement) diagram is drawn according to the assumption that both cell changes are considered simultaneously and in continuity.

5- Results

The results of the theoretical method were consistent with the results of numerical simulation with a maximum error of about 16% in the parameters discussed, including impact force, absorbed energy, maximum velocities, maximum displacements, maximum strain and the final angles for the absorber rods in both single and double cell modes.

According to the theoretical assumptions and numerical simulations in the double cell absorber, it is concluded that in this mode, without having a significant effect on maximum force, the energy absorption rate increases because of an increase in the area below the displacement graph, compared with the single cell mode.

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