Analysis of the Energy Absorption Capacity of the Caladine-English Folded Plate Energy Absorber

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Date: 2020-10-13T00:00:00+00:00

Abstract

Building upon the work of Zhang-Yu, this paper conducts a detailed analysis of the energy absorption capacity of the Caladine-English folded plate energy absorber. We developed a general-purpose program using Maple software for the Zhang-Yu energy absorber equations of the Caladine-English folded plate energy absorber, and obtained for the first time the time evolution of the absorber’ s generalized coordinates (rotation angles). On this basis, a comparative study was performed on the influence of various parameter variations on the energy absorption capacity of the Caladine-English folded plate energy absorber, for which an energy absorption factor was defined to characterize the structure’ s energy absorption capability. To better understand how parameter variations affect the absorber’ s motion, we computed the phase portrait of the absorber dynamics. Through extensive numerical simulations, it was found that, from the perspective of energy absorption capacity, the 4-fold plate absorber should be a `mass-sensitive'' type absorber, which fully supports Zhang-Yu's conclusion: namely, that the Caladine-English folded plate energy absorber is` amass-sensitive’’ type absorber.

Full Text

3.1 Dynamic Response Analysis of the Calladine-English Model

The dynamic response of the Calladine-English model was analyzed using both rigid-viscoplastic and rigid-plastic formulations. Numerical simulations were performed for three initial folding angles: $_0 = 1.146°$, $_0 = 2.6°$, and $_0 = 4°$. The governing equations were solved using Maple’ s rkf45 Runge-Kutta method with appropriate initial conditions.

The system parameters were defined as follows: b = 51 mm, h = 1.6 mm, 2L = 50 mm, m = 0.016 kg, and M_0 = 9.79 N · m. The impact energy was fixed at U_0 = 122 J, with the drop weight G and impact velocity V_0 varied according to seven parameter combinations listed in Table 3 . The initial angular velocity was determined from the impact conditions using the relation $\dot{\theta}_0 = GV_0 \sin\theta_0/[m/3 + (m + G)\sin^2\theta_0]$.

Figure 3 [Figure 3: see original paper] shows the angular displacement (t) for the rigid-viscoplastic model with $_0$ = 1.146° under all seven parameter combinations from Table 3. The corresponding response for the rigid-plastic model is presented in Figure 4 [Figure 4: see original paper]. Similar comparisons for $_0$ = 2.6° are shown in Figures 5 [Figure 5: see original paper] (viscoplastic) and 6 [Figure 6: see original paper] (plastic), while Figures 7 [Figure 7: see original paper] and 8 [Figure 8: see original paper] display the results for $_0$ = 4°. The Maple code implementation for these simulations is provided in Table 2 , which illustrates the piecewise definition of the moment-rotation rate relationship according to the Cowper-Symonds constitutive law.

3.2 Parametric Studies of Impact Velocity and Drop Weight

The influence of impact velocity V_0 was investigated while maintaining constant impact energy U_0 = 122 J. Phase diagrams of versus d /dt were generated for both material models at two initial angles. Figure 27 [Figure 27: see original paper] shows the rigid-viscoplastic response for $_0$ = 1.146° with V_0 varying from 1 to 10 m/s, while Figure 28 [Figure 28: see original paper] presents the corresponding rigid-plastic case. For $_0$ = 4°, the phase diagrams are shown in Figures 29 [Figure 29: see original paper] (viscoplastic) and 30 [Figure 30: see original paper] (plastic). These results demonstrate that higher impact velocities produce more rapid initial rotation rates, though the total rotation is constrained by the fixed impact energy.

The effect of drop weight G was similarly examined. Figures 31 [Figure 31: see original paper] and 32 [Figure 32: see original paper] compare the -d /dt phase diagrams for viscoplastic and plastic models with $_0$ = 1.146° and G varying as 4i kg (i = 1 to 10). The corresponding results for $_0$ = 4° are presented in Figures 33 [Figure 33: see original paper] and 34 [Figure 34: see original paper]. The analysis reveals that for a given impact energy, heavier drop masses produce lower peak rotation rates but similar final angular displacements.

3.3 Influence of Structural Mass and Mass Ratio

The structural mass m was varied independently to assess its effect on the dynamic response. Phase diagrams for m = 0.01 · i kg (i = 1 to 10) are shown in Figures 35 [Figure 35: see original paper] and 36 [Figure 36: see original paper] for $_0$ = 1.146°, and in Figures 37 [Figure 37: see original paper] and 38 [Figure 38: see original paper] for $_0$ = 4°, covering both viscoplastic and plastic formulations. The results indicate that increasing structural mass reduces the angular acceleration for a given impact condition.

The combined effect of mass ratio m/G was also analyzed. Figures 39 [Figure 39: see original paper] through 42 [Figure 42: see original paper] present phase diagrams for various m/G ratios, showing how the relative magnitude of structural mass to drop weight influences the energy transfer efficiency and deformation mode. The mass ratio emerges as a critical parameter governing the inertia effects in the Calladine-English model.

4 Discussion and Conclusions

The numerical simulations demonstrate several key characteristics of the Calladine-English energy-absorbing structure:

1. **Strain Rate Sensitivity**: The viscoplastic model consistently predicts higher moment resistance than the plastic model due to rate-dependent material behavior, particularly evident at higher rotation rates.
2. **Inertia Effects**: The dynamic response shows significant inertia effects, especially for small initial angles ($_0 < 2°$), where the rotational acceleration is most sensitive to impact parameters.
3. **Energy Conservation**: The total energy absorption capacity remains consistent across different parameter combinations when U_0 is fixed, though the deformation history varies substantially.
4. **Parameter Interdependence**: The initial folding angle $_0$, drop weight G, impact velocity V_0, and structural mass m exhibit complex interactions that determine the final deformation mode and energy dissipation distribution.

The results validate the theoretical framework established by Calladine and English [1,27] and extend previous work by Zhang and Yu [2] through comprehensive parametric analysis. The findings are consistent with experimental observations reported in [30,31,33] regarding inertia and strain-rate effects in impact-loaded structures.

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