ADAPTIVE IMPACT ABSORBTION CONTROLLED VIA PYROTECHNIC DEVICES

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This article introducing a new idea of local heuristic structural control algorithm for preserving the structural integrity during impact process. Also the paper proposes concept of technical realization of pyrotechnically controlled linear brake element. Simulation results and algorithm details are provided.

Keywords: structural control, heuristic algorithms, impact, pyrotechnic, actuator, Adaptive Impact Absorption, AIA

Introduction

A motivation for the research is to follow a new direction, visible in the region of structural impact and crashworthiness, where structural adaptation can improve behavior of a system/structure subjected to a heavy dynamic load . Typically, present solutions for impact problems are based on passive behavior of impacted objects. The "Adaptive Impact Absorption" (AIA) systems [1] are based on embedding the control system to govern the energy absorber. For example the adaptive landing gear [2] or adaptive frontal structure of the vehicle [3] may be quoted. In this paper structural control algorithms and early stage concept of heuristic control of the structure based on pyrotechnic devices will be demonstrated.

1 Problem formulation

Making an assumption of an isolated, discrete spatial truss-like structure Γ in Euclidean space $X=(x,y,z) \in \boldsymbol{R}^3$ with Cartesian coordinate system, consisting of i–th number of mass-less structural members Ψ_i, hereinafter called the elements and j–th number of nodal points Φ_j, hereinafter called the nodes. Every structural member Ψ_i is capable to transfer forces only at translational degrees of freedom to two arbitrary affiliated nodal points i_j^1 and i_j^2. Some arbitrary pre-selected nodal points Φ_j may be constrained with translational boundary conditions, zeroing all time derivatives of their spatial coordinates BC: $\partial X/\partial t=0$. Connection to nodal points and their BC remain constant for total time of observation. The element force-displacement response $P(l_i, F_i)$ is given as a function of distance between element's nodal points coordinates d_{ij} and control function $F_i(t,p_1,p_2,..p_n)$.

The element characteristics is given by the combination of elastic-perfectly plastic or elastic-frictional constitutive law with modifications governed by the control function $F_i(t,p_1,p_2,..p_n)$.
The structure is subjected to impact modeled as initial velocity and lumped mass with one of the nodes, becoming the only source of energy in the system, because structural control does not add any to the object.
The objective of the control algorithm will be the maximization of maximal internal energy E_i during impact

$$\max \sum_i \int P_i(l_i, F_i) dl_i = E_i \ , \tag{1}$$

with the constraint defined as the maximal allowed elongation of each element

$$|l_i| < d_{\max} \ . \tag{2}$$

2 Possible control methods

Integrity of the elastic-plastic truss-like structure, which elements are not subjected to local loss of stability, is menaced when the local plastic strains are reaching the maximal values (c.f. eq.2). Extension of single element's plastic strain is caused by influence of neighboring elements' forces transmitted through affiliated nodes. Localization of plastic strain regions in passive, elasto-plastic continuous structures varies depending of impact velocity and boundary conditions [5]. Even if the modification of the passive structure, based on the proper variation of element yield stresses, can provide adequate efficiency in the impact process for which it was designed, then the structural behavior in different cases of loading may not meet the initial expectations. The disadvantage can be eliminated by use of the smart structure based on the AIA system ideas. Such structural self-control algorithms may be formulated for whole structure, being applied through main control unit or just act on the local level. Total efficiency of the self-control algorithms can be increased through the fact that algorithm can modify the structure in the real time, adding some dynamic effects to the impact absorption process.

3 The LoHIC algorithm

In an attempt to resolve the problem formulated above a new local heuristic control algorithm has been developed. The algorithm, called LoHIC (**Lo**cal **H**euristic **I**mpact **C**ontrol), is aimed at preventing of destruction of the single structural element (the master element) by reducing yield stress levels of the neighboring ones (slave elements), which influence to the plastic deformation of controlled element were heuristically assessed as the greatest. General scheme visualizing LoHIC algorithm's idea is shown on Figure 1.
It was assumed that if the element's plastic strain ε_p exceeds a certain value arbitrarily assumed to ε_1, the control of yield forces of neighboring elements becomes switched on. When the strain of any of the elements reaches the value of ε_2, the control of its yield force from the outside is impossible. After crossing the

plastic strain ε_3, the yield force is reverted to the original level Y_{high} (if it has been previously reduced). Properties of element characteristics are shown in Figure 2.

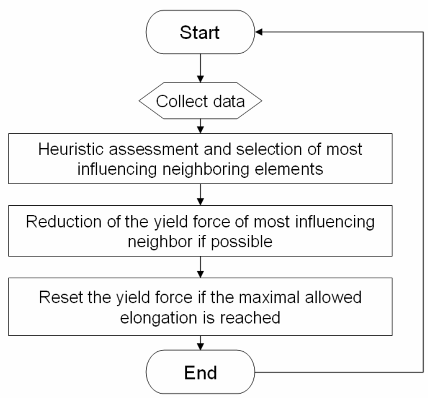

Figure 1: General scheme of LoHIC algorithm

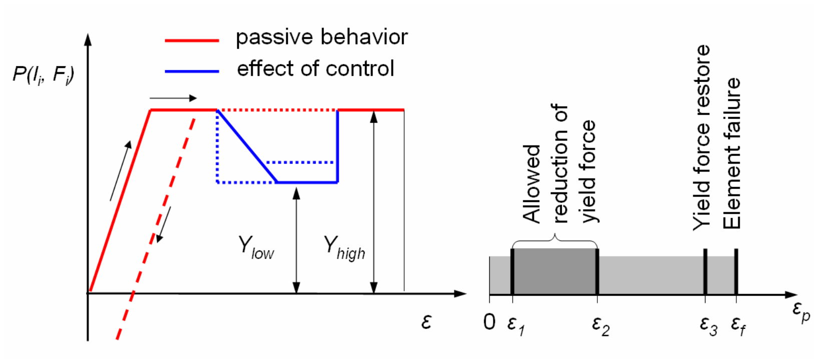

Figure 2: Properties of element characteristics

Selection of the slave element with the highest influence on the plastic strain in the master element is performed on a set of the axial forces form the neighboring elements projected to the master element's axis independently for each node. Additionally other information about slave elements, like plastic strains or plastic strain rates, are collected in sets P_i^* together with each slave element force history.

After slave elements data collection stage, where assembled parameters are determining the status of slave elements as well as their influence to the master element, the low-pass filtering operation is being performed, based on the signals saved from previous steps. The aim of the filtering operation is to eliminate all high frequency noises and vibration components from the data.

Next step is devoted to comparison of the energy absorbing capability of the previously pre-selected slave element with the master element and second pre-

selected slave element belonging to opposite node. This operation switch the control function to the element in the neighborhood which status is less deformed. Two versions of the algorithm were developed: continuous which reducing slave elements yield forces proportionally to time when the control conditions are met, down to Y_{low} and discrete which modifies yield forces jumping directly to predefined Y_{low} level.
Finally, in the situation when the element is exceeding the maximal allowed low level plastic strain, its own yield force is being raised to the initial level Y_{high} to harden the element response and decelerate the element deformation process.
Described procedure is performed in a loop on all elements belonging to the structure.

4 Simulation results of semi-heuristic local-self control algorithm

The LoHIC control algorithm was implemented to the C + + object-oriented simulation code, using explicit time integration method. Calculations were performed with use of large displacement formulations and constitutive nonlinearities, with time step h=1e-6 s. For demonstrational purposes the truss-like structure in shape of cantilever beam was loaded with initial velocity V=200 m/s applied with lumped mass m=200kg to one node (Figure 3). The translational degrees of freedom of the two nodes at the right- hand side of the beam were constrained $(\partial\Omega/\partial t)=0$.

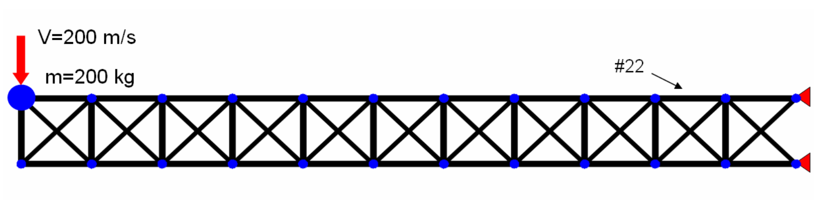

Figure 3: Model used for simulations

Lumped masses of remaining nodes are set to 1kg, elastic modulus K=2E7 N/mm and the highest level of friction force is Y_{high} *=500E4 N*. As the basic assessment criteria of efficiency of the LoHIC algorithm, the amount of structural internal energy E_i at the moment of failure of first structural elements was used. The E_i is defined as the sum of elastic potential energy E_e and dissipated energy E_d

$$E_i = E_e + E_d \quad . \tag{3}$$

Maximal plastic strain $\varepsilon_{max}=15\%$ was assumed as the failure criteria.
Structures under LoHIC control are compared to passive case when all yield forces are not subjected to any modification. Thickness of the element line in figures presented below is proportional to the current element's yield force level value, whereas amount of dissipated energy is proportional to the area of a circle positioned at the center of the element. Optimization of LoHIC control parameters was obtained through the use of evolutionary algorithms.

4.1 The passive structure

Simulation results consisting of mode of deformation, distribution of dissipated energy and yield levels, performed on the structure without any modification are depicted in Figure 4. The passive structure was used as a reference for comparison with controlled ones.

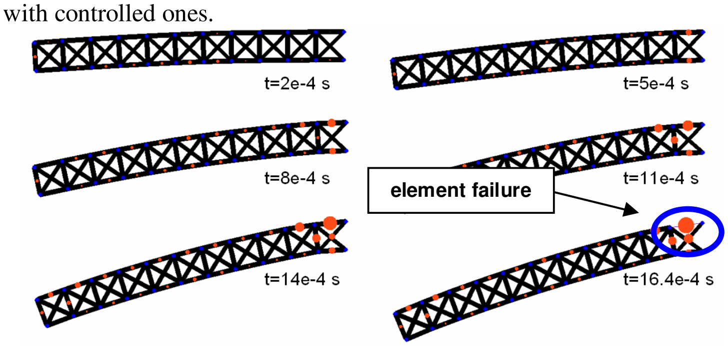

Figure 4: The passive structure

4.2 The LoHIC control

Simulation results consisting of mode of deformation, distribution of dissipated energy and yield levels, performed on the structure controlled by LoHIC continuous algorithm are depicted in Figure 5, with Y_{low} *=10%* Y_{high}. Results obtained with LoHIC discrete algorithm are depicted in fig xx, with Y_{low} =40% Y_{high} are depicted in Figure 6.

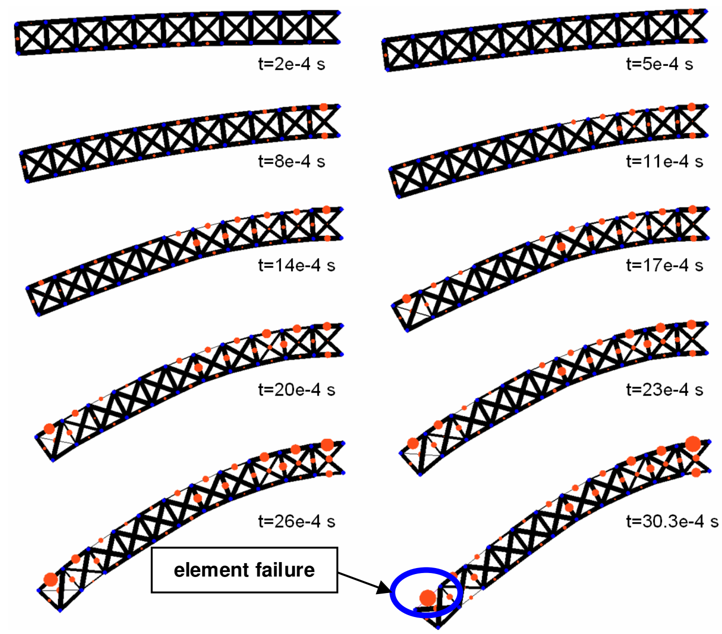

Figure 5: The LoHIC continuous governed structure

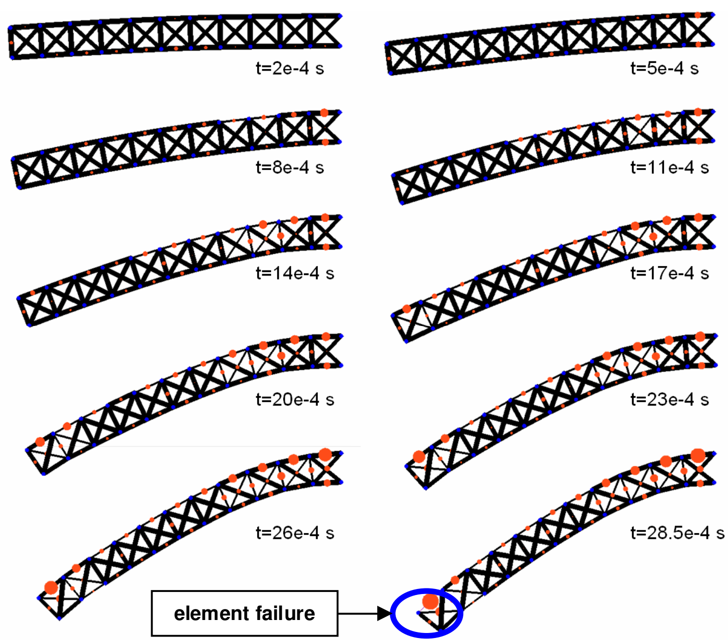

Figure 6: The LoHIC discrete governed structure

4.4 The simulation results summary

Results form all simulations are shown in the Table 1. Comparing to passive structure, both version of the LoHIC algorithm extended the maximal energy absorbing capability up to 86% in case of continuous version of algorithm. Decelerations of impacted node and example element force histories are shown in Figure 7

Table 1: Comparison of simulation results

	Internal energy at failure [J]	Impacted node penetration [mm]	Time of failure [s]
Passive structure	2.56e5	320	16.4e-4
Continuous control	4.77E5	576	30.3e-4
Discrete control	4.52E5	551	28.5e-4

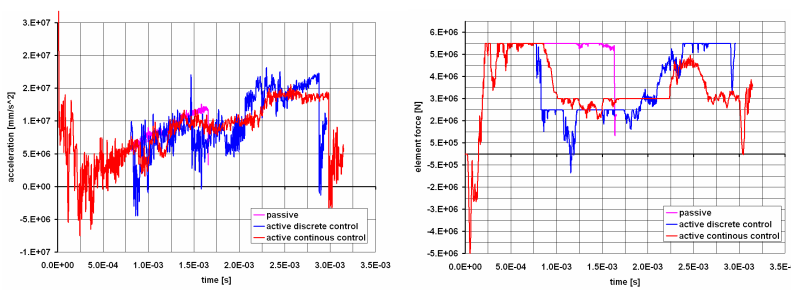

Figure 7: Plots of acceleration of impacted node and force history form element #22 as functions of time

4 Pyro-actuators technology

Pyrotechnic driven actuator technology is proposed as a way of technical realization of discrete control strategy described in the paper. The continuous control is more complex to obtain with current technologies and its technical implementation will not be discussed here, however it seems that the magnetho-rheological dampers could be studied for this application in future [4]. Envisaged concept of element capable to provide elastic- plastic response with two levels of yield force, which is essentially controlled linear brake, is presented in Figure 8.

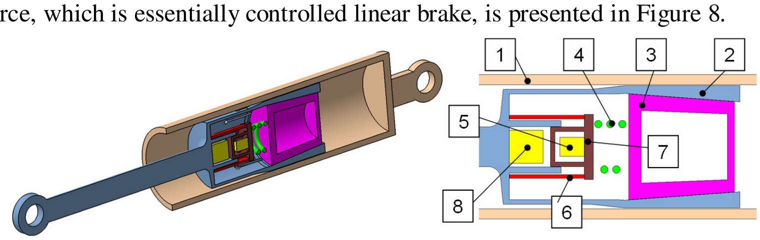

Figure 8: The pyrotechnically driven controllable linear brake

The proposed solution of pyrotechnically controlled linear brake consists of: outer cylinder (1), which internal surface is a part of the brake's frictional pair and assembly module of the internal brake rod witch built-in prestressing device and pyrotechnical control unit. Main operation part - the internal brake assembly module is composed of: conical pressing part (3) spreading the expandable spring collet becoming a second part of the frictional pair of the brake (2). Also the prestressing coil spring (4), which tension is controlled via the pyrotechnical-latching section are belonging to the internal brake assembly. A function of the pyrotechnical-latching section is to reduce the spring prestress force after the operation of first pyrotechnic gas generator (5), which chemical products of inflagration act with high pressure on internal surface of expandable latch sleeve (6), causing its expansion and allowing the piston insert (7) to move decreasing spring prestress force and lowering the same braking force of the system.
After receiving the increase braking force signal, the second gas generator (8) chemical products of inflagration exert pressure on the piston insert causing its movement to the previous position, what prestress again the coil spring to the initial value. When the piston insert translates to the suitable position, the expandable latch sleeve shrinks backs due to its elasticity, fixing the piston insert in the initial position. As a result the breaking force is switched back to the initial value.

Conclusion

The concept of self-control structural algorithm, allowing to be used for structures with large displacements and constitutive nonlinearity, was presented. It is obvious that the LoHIC algorithm does not fully meet he initial assumption of the maximization of internal energy (1), however it noticeably extends the energy absorbing capability comparing to the passive state. Further improvements can increase the efficiency and extend the application range of the method.

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