Nonlinear Dynamic Analysis of Progressive Destruction, Leveling and Repair of Multi-Story Buildings

Sergiy Fialko[1,*]

[1]Faculty of Computer Science and Mathematics, Cracow University of Technology, Kraków, Poland
e-mail: sergiy.fialko@pk.edu.pl

KEYWORDS: *Nonlinear Dynamics, Plastic Flow Theory, Finite Element Method, Damage Mechanics.*

The behaviour of structures of multi-story buildings under extreme loads arising from strong seismicity, gas explosions, drone impacts, artillery shell impacts, etc., is considered. At the first stage, the problem of progressive destruction is solved, and the proposed approach, unlike conventional methods, allows us to instantly or gradually remove the finite elements of not only spatial frames, but also finite elements of any type, including fragments of load-bearing walls and staircase-elevator blocks modelled by the finite elements of plane shells [1]. The proposed technique for adding and removing auxiliary supports, based on the method of time-dependent penalty parameters, as well as adding finite elements, allows us to simulate the leveling of a structure that has significant deformations and the replacement of destroyed finite elements with new, undamaged ones [2].

The finite element library includes quadrilateral and triangular Mindlin-Reissner finite elements, as well as a space frame finite element. In reinforced concrete, reinforcement is modeled as inclusions. For concrete, the plastic flow theory is applied, and the yield surface is assumed to be a non-circular Geniev paraboloid. In the hardening zone, the yield surface expands, and in the softening zone, it contracts. When the limiting deformations are exceeded, the destruction of concrete is modeled using the damage parameter. For steel, the von Mises plastic flow theory with kinematic hardening is adopted. When the limiting deformations are exceeded, the failure of the reinforcement is also modeled using the damage parameter. The calculation is carried out according to a deformable scheme – after each converged time step, the nodal coordinates are updated using nodal displacements.

As a result, we obtain the Cauchy problem:

$$\begin{gathered}\mathbf{M}(t)\ddot{\mathbf{u}} + \frac{d\mathbf{M}}{dt}\dot{\mathbf{u}} + \mathbf{C}\dot{\mathbf{u}} + \mathbf{f}^{int}(\mathbf{u},t) + \mathbf{\Gamma}(t)\mathbf{u} = \mathbf{f}^{stat} + \mathbf{f}^{dyn}(t) + \mathbf{\Gamma}(t)\hat{\mathbf{u}}(t) \\ \mathbf{u}(0) = \mathbf{u}_0, \;\; \dot{\mathbf{u}}(0) = \mathbf{v}_0\end{gathered} \quad (1)$$

Here $\mathbf{u}$ is the vector of nodal displacements, $\mathbf{M}$ and $\mathbf{C}$ are the mass matrix and dissipation matrix, $\mathbf{f}^{int}(\mathbf{u},t)$ is a nonlinear operator returning the vector of internal forces, $\mathbf{\Gamma}(t)$ is the diagonal matrix of penalty parameters, $\mathbf{f}^{stat}$ is the vector of static loads, $\mathbf{f}^{dyn}(t)$ is the vector of dynamic loads, $\hat{\mathbf{u}}(t)$ is the vector of imposed displacements. The derivative $\frac{d\mathbf{M}}{dt}$ appeared because the mass matrix changes over time when finite elements are removed/added. The Cauchy problem is solved numerically using the implicit α-HHT method. Details are presented in [1, 2].

ACKNOWLEDGEMENT: The author expresses gratitude to SCAD Soft (www.scadsoft.com) for financial support of this work.

[1] S. Fialko. Progressive Collapse Analysis on Multicore Computers Using Nonlinear Dynamic Approach, Comp. Assist. Methods Eng. Sci. **31**(4), 449–486, 2024. https://doi.org/10.24423/cames.2024.1641

[2] S. Fialko. Finite Element Modeling of Collapse, Leveling and Repair of Multi-Storey Buildings Exposed to Extreme Impacts, Comput. Struct. **325**, 1 – 10, 2026. https://doi.org/10.1016/j.compstruc.2026.108197