Dynamic Energy Balance Approach to Progressive Collapse Prevention

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Summary

Physics based collapse simulations of moment resisting steel frame buildings are presented with an emphasis on the development of energy flow. It is proposed that energy flow during progressive collapse can be used in evaluation of moment resisting, steel frame building behavior and specifically, localized failure. If a collapsing structure is capable of attaining a stable energy state through absorption of gravitational energy, then collapse will be arrested. Otherwise, if a deficit in energy dissipation develops, the unabsorbed portion of released gravitational energy is converted into kinetic energy and collapse propagates from unstable state to unstable state until total failure occurs. The energy absorption of individual members provides very transparent information on structural behavior as opposed to oscillating internal dynamic forces in structural members. Therefore, critical energy absorption capacity is hereby proposed as a stable failure criterion in progressive collapse analysis. Energy flow quantification is shown to be readily available from the dynamic finite element simulations. The proposed dynamic, energy based approach to progressive collapse, provides insight and a simple yet robust analysis for producing structures capable of resisting abnormal loadings and/or unexpected hazards.

Keywords: progressive collapse, energy flow, steel framed building, numerical simulation, robustness, disaster prevention.

Internal energy (deformation work) flow

The main objective of this study was to develop and implement a rational, energy-based approach to progressive collapse of steel framed buildings by assessing individual members and full structural behavior focusing on the role of energy flow in these phenomena.

Energy flow based approach was used to analyze the response of the three-story steel framed building (Fig. 1) to sudden columns removal. Special emphasis was put on column behavior because the corresponding crucial role in the collapse propagation or arrest. Three columns were instantaneously removed after application of static preloading. Sudden removal of the columns resulted in partial collapse. Significant levels of kinetic energy were observed in the building, and internal energy (deformation work) of the system increased by more than 2000%. Kinetic energy began to diminish as bays with removed columns impacted the ground layer. System achieved a stable energy state when kinetic energy vanished.

Buckling energies are characteristic values of columns, and failure energy limits are fundamental properties of a structure (dependent both on column properties and on a value of permanent load). Both buckling energy and column failure energy were computed prior to the full building simulation, using the numerical (LS-DYNA) calculation procedures.

A comparison of the force demand to the member capacity is traditionally employed to evaluate a member's safety. It has been shown in this study that force based demand capacity (D/C) is not very sensitive to the fundamental changes in structural behavior. Conversely, buckling energy D/C values correctly identified buckling in all analyzed cases in spite of complex interactions between

https://doi.org/10.2749/222137809796068118

axial forces and bending moments. Moreover, the energy failure D/C criterion was violated only by failed columns. In the case of arrested collapse, comparing the energy absorbed (deformation work) in a given column to the failure limit enabled direct evaluation of the column and building safety.

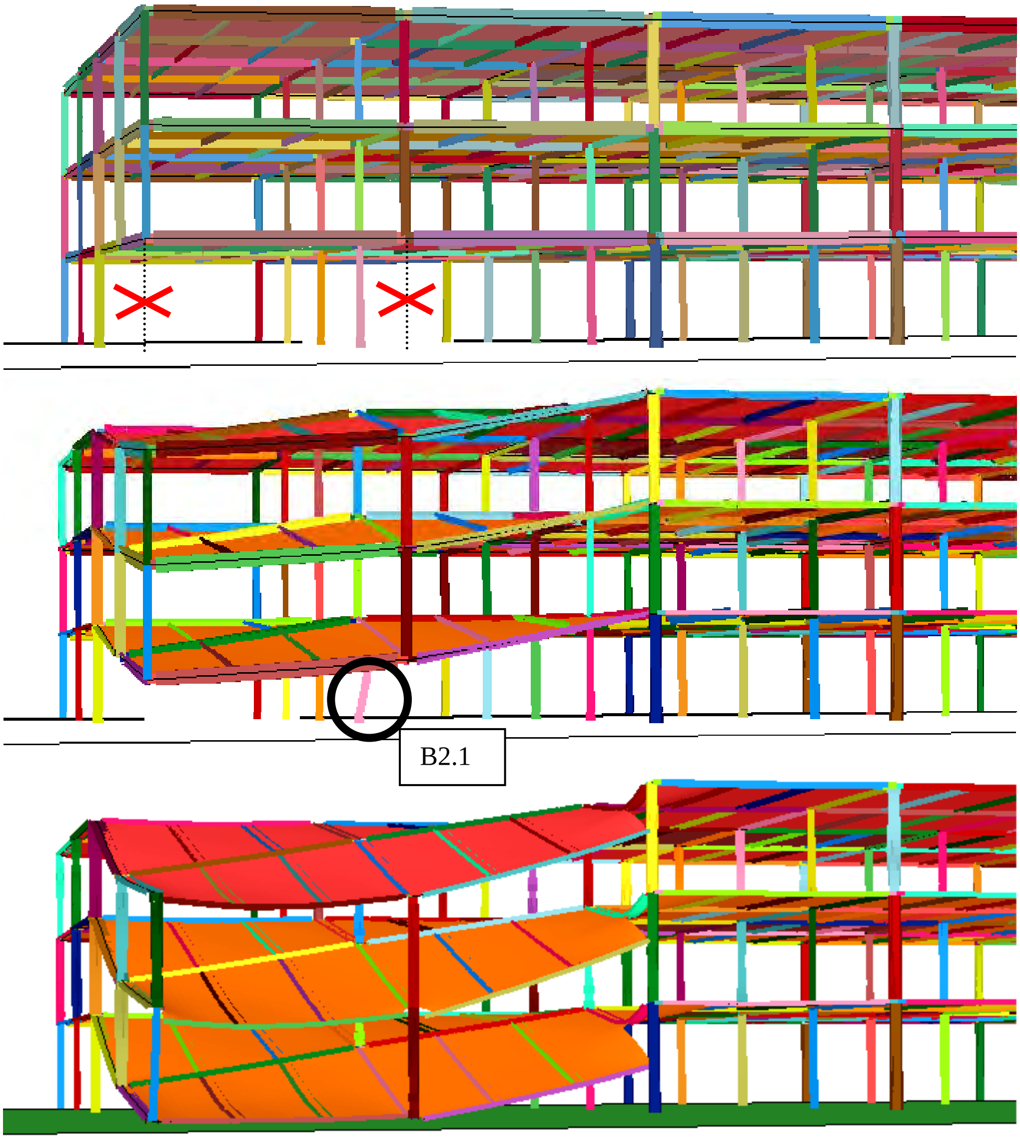

Fig. 1: Collapse sequence of the steel building after removal of three columns