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Dynamic analysis methodology for progressive failure of truss structures considering inelastic postbuckling cyclic member behavior

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ABSTRACT

Over the years, several catastrophic collapses of truss structures have been reported. Sudden failure or reduction in member capacity of a single member in a truss structure gives rise to dynamic force redistribution in the remaining members and may lead to progressive collapse of the entire structure. During failure, truss members can undergo inelastic cyclic behavior (including postbuckling in compression and yielding in tension) that may not have existed in the intact structure. This paper presents a methodology to incorporate the inelastic cyclic member force–deformation behavior in the dynamic analysis of truss structures and at the same time incorporates the possible dynamic effects arising from the sudden change in load carrying capacity of a member due to failure or buckling/postbuckling. The method tracks and generates the force–deformation characteristics of every member of the truss at each incremental time step. The continuous change in the load-carrying capacity and the stiffness of members during the nonlinear force–deformation history has been incorporated in the analysis scheme using the Pseudo-force approach. The solution methodology for obtaining the dynamic response of the structure is based on the finite element technique and considers elasto-plastic material and large deformation geometric nonlinearities. The methodology is applied to a two-dimensional three-member toggle redundant truss subjected to external static, quasi-static, and dynamic (sinusoidal and ramp) loads. Results delineating the effects of the inelastic cyclic axial force–deformation relation of each member and the time variation of joint displacements and member forces are presented for each loading condition. The results show that there exist cases where modeling a compression member with its actual postbuckling behavior, which although has some reserve load carrying capacity, are more critical than the case where the same member is considered to suddenly lose its full load carrying capacity at its buckling load.

1. Introduction

Progressive collapse is a failure mechanism of structures. The term progressive collapse refers to the failure of a single element or small portion of the structure which leads to an unstable condition for the overall structure and results in overstressing and consequently failure of other elements. Successive elements fail one after another which leads to the total collapse of the whole structure. In recent years, several catastrophic failures of structures occurred due to progressive collapse mechanisms. The most famous examples are the collapse of World Trade Centers (WTC) and the collapse of I-35W Steel Deck Bridge over Mississippi River in Minneapolis. Forensic investigations of the collapse of the World Trade Center [1–4] revealed that after the intense fires that followed the impact, either the floor supports at the impact zone failed or the vertical columns at the impact location buckled. Whichever occurred first, in each case at least one floor collapsed onto the floor below, leading eventually to progressive column buckling and successive collapse of the whole structure. The post failure investigations by Astaneh-Asl [5] and Melchiorre [6] of the I-35W steel bridge reveals that the collapse was initiated due to the loss of one single gusset plate on the bottom chord connection. This led to the entire collapse of the bridge within few moments resulting in deaths of 13 people and injury to more than 100 others.

The vulnerability of structures to progressive collapse after a blast event has become a growing concern in the construction industry. Investigators [7–11] have studied the progressive failure mechanisms for different structures such as composite laminated structures, orthotropic bridges etc. There is an international trend for updating structural design requirements explicitly to design structures to resist progressive collapse. Several government agencies [12,13] set up specific criterions for incorporating the progressive collapse mechanism for analyzing building structures. Several design codes were recently updated to include specific clauses which require structural integrity of the structure to rule out the possibility of progressive collapse.

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