Simplified Collapse Analysis of Structures using the Extended Distinct Element Method and Finite Element Mapped Spring Network

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ABSTRACT

Collapse analysis of buildings is invaluable in the field of Urban Disaster Reduction and there are various scientific methods for collapse analysis. However, these methods are usually complicated and time consuming to be used in actual practice. In this study, a two-phase analysis scheme is proposed namely; (i) Finite Element Mapped Spring Network phase, and (ii) Extended Distinct Element Method phase. The former uses an implicit numerical scheme and predicts the initial behavior accurately, whereas, the latter models the separation, collision and collapse efficiently. By combining these two methods, it is possible to model efficiently, the complete behavior of a building subjected to seismic loading, i.e. from its initial state to a complete collapse state.

Introduction

Numerical simulation of the complete behavior of a building after the onset of an earthquake is important for understating its vulnerability to a seismic hazard and for providing necessary mitigation measures. There are various scientific methods to simulate the collapse of a building, however, they usually tend to be computationally extensive and complicated for practical vulnerability analysis of buildings. For ease of such analysis, the preferred characteristics are simple modelling, less computational expense, easy visualization and accuracy. The Distinct Element Method (DEM) [1] was initially introduced to model highly discontinuous and granular media, which comprised of domain discretization using rigid elements with springs at the point of contact. The approach of discretizing the structure into an assemblage of discrete elements and springs [2-4] is highly preferable due to its ability to capture element separation (crack initiation and propagation), with ease of modelling and lesser computational requirement as compared to continuum based analysis techniques such as the Finite Element Method (FEM).

In order to simulate total failure behavior from continuum to discrete medium, the Modified (or Extended) DEM [5-7] was developed by introducing pore (or joint) springs that represent the continuous material media between elements (Fig.1).

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The EDEM has been used to simulate concrete fracture [5, 6] and structural collapse [7]. However, it has few limitations, namely (i) requirement of a small time step for stability and accuracy due to the use of explicit time integration scheme, (ii) no proper mechanics theory for spring parameter derivation, hence less accuracy in the initial linear and nonlinear stage, and (iii) inaccuracies in handling Poisson’s ratio. This study involves in addressing these limitations by the application of a finite element mapped spring network system in the initial phase of analysis (linear, non-linear). By the combination of these two methods, a simplified complete collapse analysis of a building could be obtained.

**Analysis Phase**

The analysis of the structure comprises of two phases: (i) Finite Element Mapped Spring Network Phase, (ii) Extended Distinct Element Method Phase. The overall behavior of the building from normal state to complete collapse state can be captured by these two phases (Fig. 2).
Finite Element Mapped Spring Network Phase

In this phase, the circular elements are connected through their centers only by the pore springs. The assembly of springs represents a spring network with lumped mass. The Finite Element (FE) mapping scheme for spring network representation of mechanics of solids [8], presented a rigorous method for spring stiffness derivation for any anisotropic infinite media. It essentially uses the property of translation invariance of the global stiffness matrix to equate the stiffness matrices obtained from finite element analysis and spring network assembly. Through this mapping procedure, the global stiffness matrix for the spring network is exactly the same as the global stiffness matrix obtained by finite element discretization.

The following advantages are obtained: (i) Due to global stiffness matrix assembly, an implicit time integration numerical scheme can be used, thereby increasing the critical time required for stable analysis, (ii) Accurate spring constants derivation, hence accuracy in the initial phase is high, (iii) Poisson’s ratio is implicitly included, and (iv) Mass matrix is diagonal, which makes its inversion during dynamic analysis trivial.

Extended Distinct Element Method Phase

Once the deformations are considerable, the analysis switches to the conventional EDEM phase. The contact springs and the pore springs work at tandem and an explicit step-by-step time integration scheme is used for dynamic analysis. The advantage of this phase is that highly non-linear behavior, cracking, separation, collision and collapse can be captured in this phase efficiently. In discrete analysis, dynamic contact detection takes the majority of computation time [9], however since the elements used in this analysis are simple circular/spherical elements, there is a large reduction in computation cost involved in contact detection during separation and collision.
Conclusions

A simplified analysis tool for numerical simulation of collapse of buildings is presented. The advantages of this method lie in its simplicity and ease of modelling. With the necessary material models, this model can be extended to model nonlinear isotropic materials like concrete. The main aim of this research is to model the collapse of reinforced concrete framed buildings with masonry infill, with relatively lower computation cost and better accuracy. The two phases complement each other and the criteria for the shift between the two phases has to be chosen based on the type of analysis required. Because of its simplicity in element models, visualization is also simple. This method facilitates in creating a practical tool that can be used for vulnerability analysis.

References