Simplified Collapse Analysis of Structures using the Extended Distinct Element Method with Finite Element Mapping

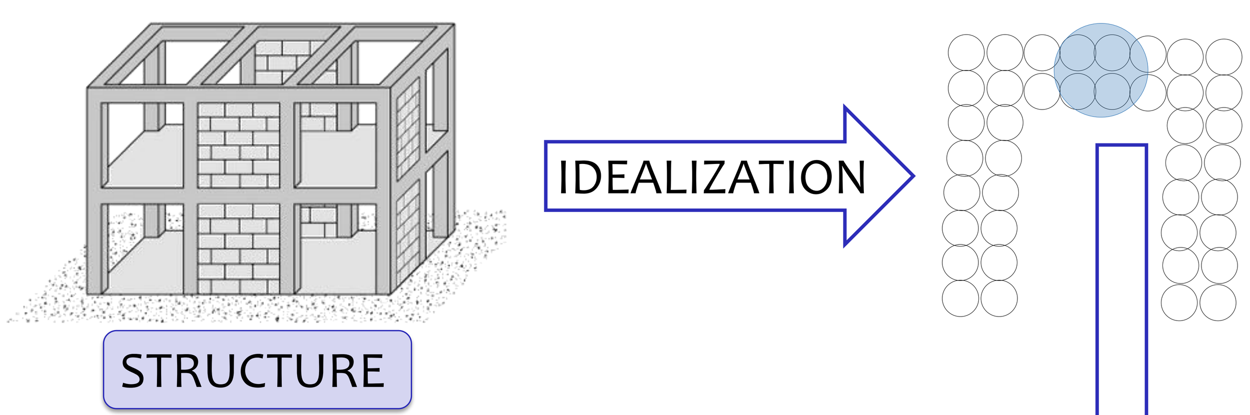
有限要素マッピングを拡張個別要素法に応用した構造物の破壊解析手法の開発

Meguro Lab.
IIS The University of Tokyo

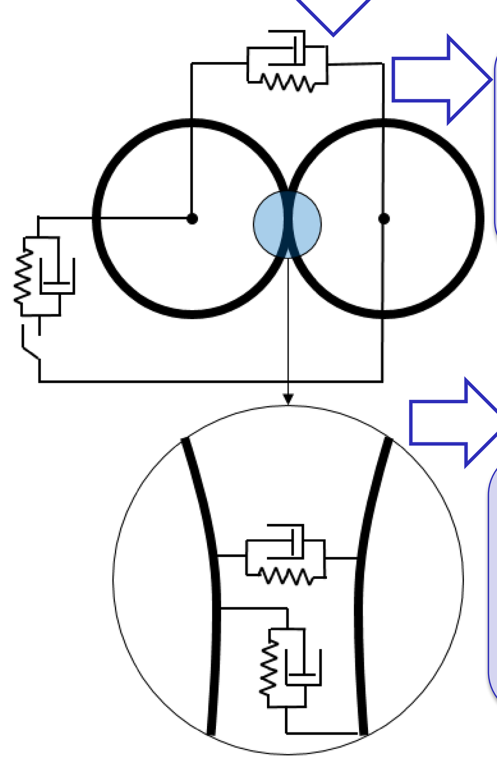
Introduction

Collapse analysis of buildings is invaluable in the field of Urban Disaster Reduction. There exists various scientific methods for collapse analysis, however, these methods are usually complicated and time consuming to be used in actual practice. There is a need for a numerical tool which is simple, accurate and computationally less expensive for practical seismic vulnerability assessment of buildings. The Extended Distinct Element Method has been observed to be a simple as well as an efficient tool for modelling collapse of structures, but it has some limitations. This study is carried out to tackle these limitations.

1. The Extended Distinct Element Method (EDEM)



Structure is idealized as an assemblage of circular / spherical elements connected by two kinds of springs viz. pore spring and contact spring



Pore Spring
A pair of normal and tangential springs acting between the center of the elements

Contact Spring
Created when two elements come into contact, it consists of a pair of springs acting between the points of contact

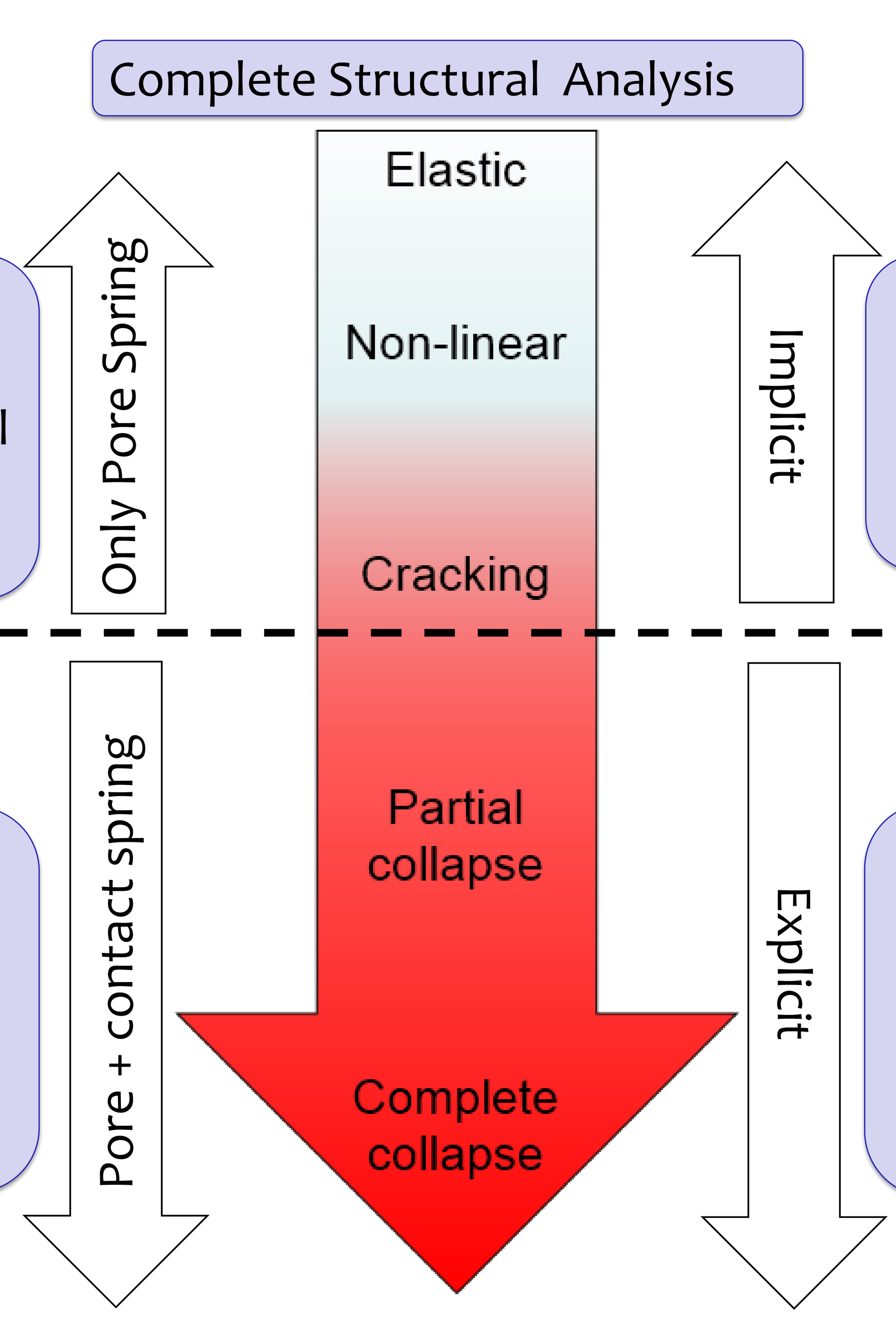
Advantages of EDEM

- Simple and easy to understand
- Simple contact detection
- Efficiently model collision and collapse of structures

Limitations and solution

Limitations	Proposed Solution
Small time step (CFL Condition)	Combined implicit-explicit computation
Inaccuracy in elastic and nonlinear phase	Finite element mapping for spring constant derivation
Inaccurate spring constants and Poisson's ratio	

2. Combined Implicit-Explicit Analysis



State 1
Represents continuum deformation until spring tensile rupture

State 2
Compressive, shear, and contact forces between the ruptured springs

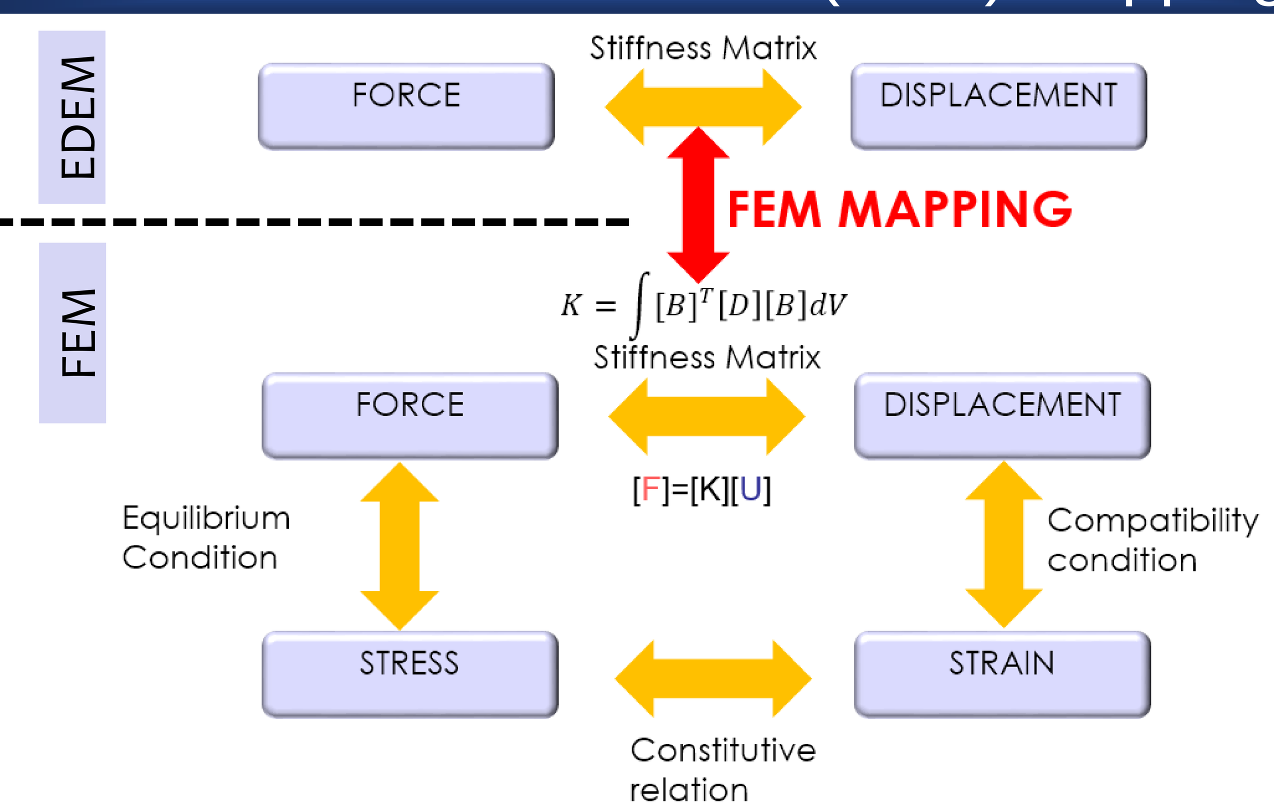
Implicit Dynamics

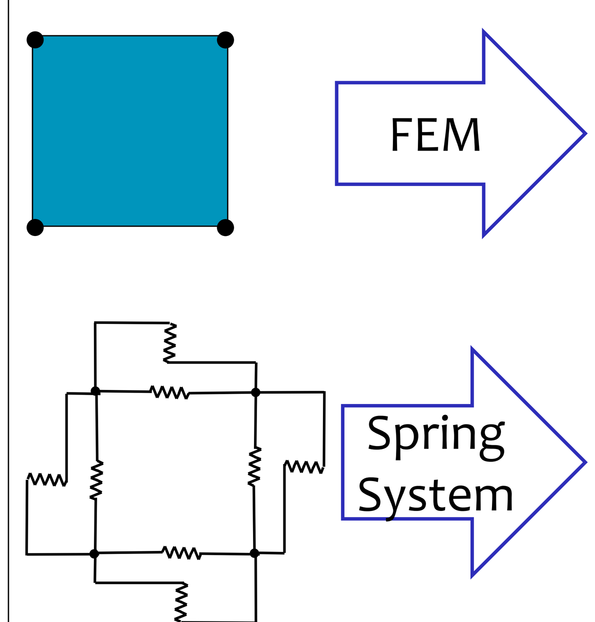
- Tangent stiffness matrix assembled every time step
- Larger time step
- Accurate and stable

Explicit Dynamics

- No stiffness matrix assembly required
- Smaller time step
- Good for contact detection (collision separation and collapse)

3. Finite Element Method (FEM) Mapping





In both cases the global assembled stiffness matrix exhibits **TRANSLATIONAL INVARIANCE** i.e. For any row (or column)

$$\mathbf{K}_{aa} = -\sum_{a \neq b} \mathbf{K}_{ab}$$

When the off diagonal blocks of both the assembled matrices are equated, it results in the derivation of spring constants. A spring system with these derived spring constant leads to an assembled stiffness matrix exactly equal to that of the FEM stiffness matrix

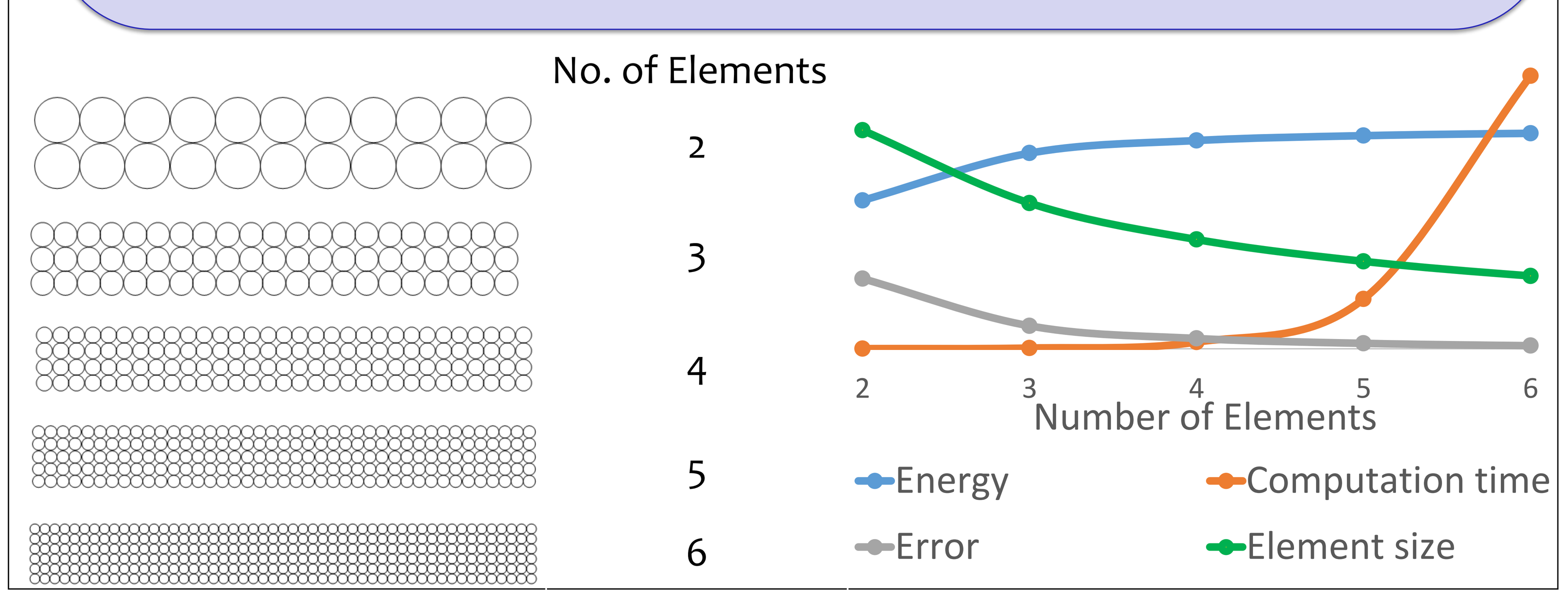
Mapping Procedure

i. Derive the Finite element stiffness matrix
ii. Derive spring network stiffness matrix
iii. Equate the off diagonal blocks of these matrices
iv. Obtain spring constants

4. Results and discussion

Linear Static Analysis

- Simple cantilever bending
- As stiffness matrix is exactly the same as FEM stiffness matrix it shows energy convergence and deflection error reduction with mesh size reduction
- Optimum balance between error and computation is required
- This modification to EDEM has (i) enabled creation of stiffness matrix (implicit dynamics, larger time step) (ii) improved the accuracy (iii) Poison ratio is considered



5. Future work

The numerical modelling of anisotropic nonlinear material like concrete and masonry needs to performed. Validation with experimental data. Extension to 3D. Implementation of parallel computation for higher computation efficiency. Creation of a user interface that can be used for practical usage. Parametric study of building collapse. Seismic vulnerability assessment of existing buildings.