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Paper No. 30. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

SIMULATION OF 3-D CONCRETE-FRAME COLLAPSE DUE TO DYNAMIC LOADING

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ABSTRACT

The extended distinct-element method(EDEM) is used to construct models of multi-degrees-of-freedom systems for particles of concrete frames and to conduct a series of numerical simulations in which the particles collapsed due to seismic forces. When a concrete frame collapses, it is reduced to a pile of debris. If the debris is rejoined to form the concrete frame, the original shape is restored; i.e., the frame prior to collapse is considered to be an assembled body of concrete debris. The EDEM is a method for analyzing discontinuous bodies, but here we report on an analysis in which concrete debris is considered to contain the elements of a discontinuous body. For convenience, we assumed that the particle shape in the debris is circular or spherical and that the parts are connected by springs that satisfy the Mohr-Coulomb yield conditions. The results of the simulations are in good agreement with records of damage done by past earthquakes.

KEYWORDS

Collapse simulation; Extended distinct-element method(EDEM)

1 Introduction

Recent studies of the collapse of concrete structures have been based on fracture mechanics(Horii and Nemat-Nasser 1986; Fanella 1990) and plasticity(Chen 1982). The distinct-element method(DEM) proposed by Cundall(Cundall 1971; Cundall and Strack 1979), however, has been used to analyze the collapse of various structures composed of granular materials such as soil and rock. Examples include the fracture of a structural foundation(Uemura and Hakuno 1987), cliff collapse(Iwashita and Hakuno 1990), rock avalanches(Uchida and Hakuno 1990), debris flows(Hakuno and Uchida 1991) and liquefaction(Hakuno and Tarumi 1988). Iwashita and Hakuno(1990) proposed the extended distinct-element method(EDEM) as a modification of Cundall's distinct-element method by adding pore springs(Fig.1) to such pore material as clay between particles. More recently, the writers proposed that an aggregate of circular elements and mortar constituent pore springs would satisfy the conditions of fracture(Meguro and Hakuno 1989). Under these assumptions, we established a model for concrete by setting these pore springs among elements and then followed the fracture process(Meguro and Hakuno 1989). The EDEM, however, has a serious drawback in that it requires an enormous amount of calculation time because explicit numerical integration is unstable unless the time step used is very short. Therefore, should this EDEM method be applied to concrete structures, an analysis of the fracture of the whole structure would be prohibitive. Therefore, we analyze only the fracture of structural members composed of few elements. To simulate the fracture analysis of a whole structure, we reduced the number of elements as much as possible. For example, for a column, two circular elements are arranged through the member cross section because at least two elements are required to resist bending moment in the column.

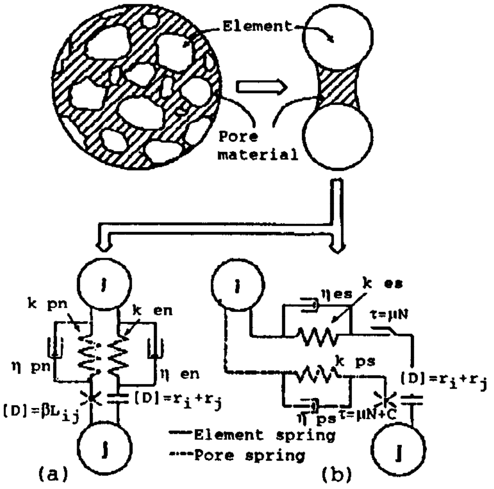


Fig. 1
EDEM modeling of concrete:(a) Normal direction;(b) Tangential direction

But, when the number of elements is drastically reduced, the model becomes oversimplified. The structure model may show a very different mode of fracture than that occurring when an actual structure fractures. I assume that a result that tells whether the structural component in question has broken down or has not broken down is satisfactory for purposes of studying fracture of the structure as a whole. Detailed information on the mode of local fracture of a particular part is sacrificed. When the number of elements is greatly reduced, the model resembles a multi-degree-of-freedom(MDOF) model common to earthquake-response analyses. The EDEM model proposed in the present study allows fracture separation to occur. Conditions in which elements become separated from one another after fracture are not allowed in analyses with MDOF models.

2 Equation of motion

The motion of a particle element i having mass $\mathbf{m}_i$ and moment of inertia $\mathbf{I}_i$ is

$$\mathbf{m}_i \ddot{u} + \mathbf{C}_i \dot{u} + \mathbf{F}_i = 0 \qquad (1)$$

$$\mathbf{I}_i \ddot{\phi} + \mathbf{D}_i \dot{\phi} + \mathbf{M}_i = 0 \qquad (2)$$

in which $\mathbf{F}_i$ = sum of all the forces acting on the particle;$\mathbf{M}_i$ = sum of all the moments acting on the particle;$\mathbf{C}_i$ and $\mathbf{D}_i$ = damping coefficients;u = displacement vector; and ϕ = angular displacement.

The dynamic response of the structure can be obtained in the time domain by step-by-step numerical integration of the equations of motion.

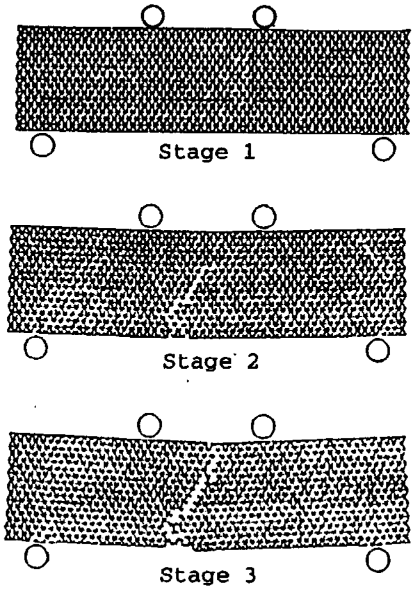
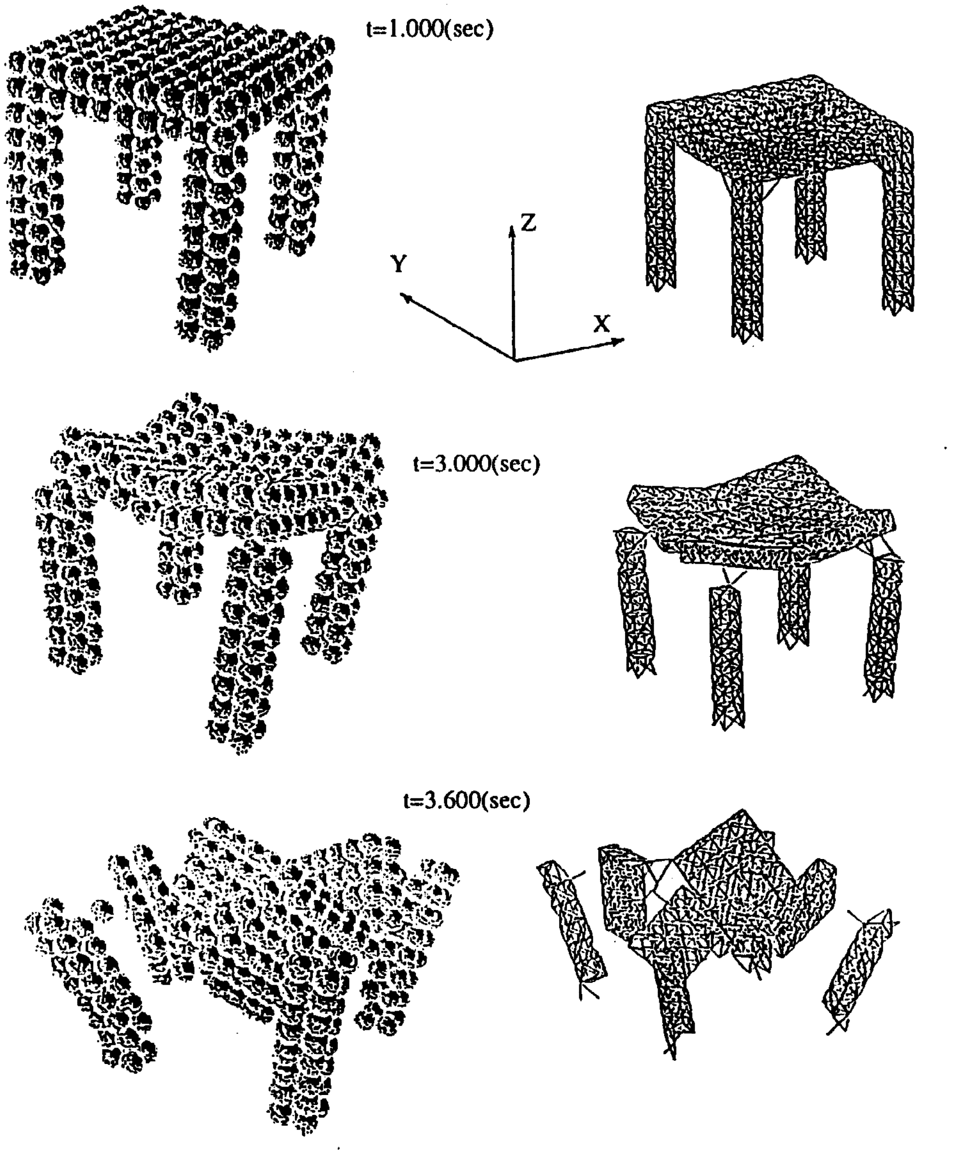


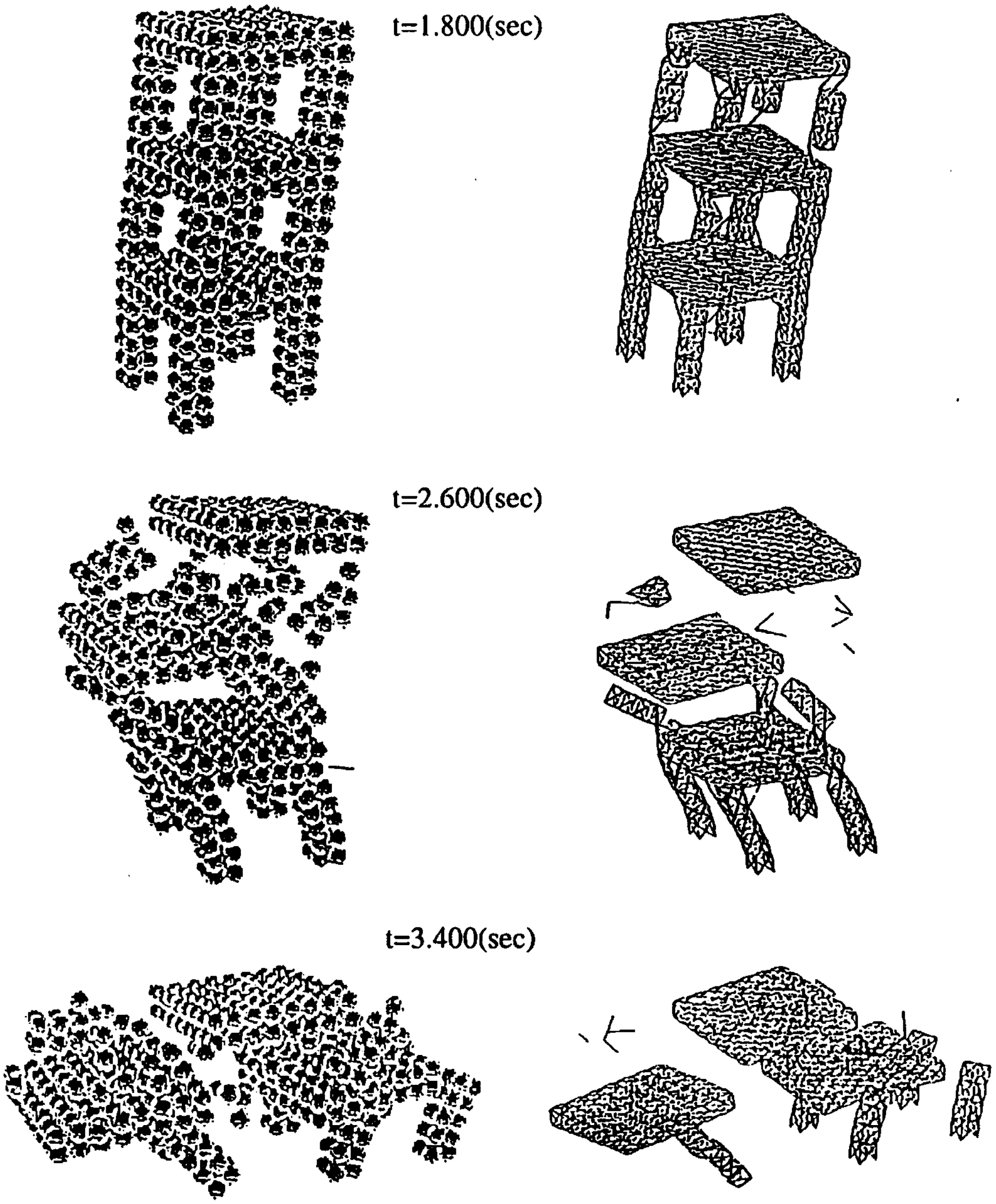
Fig. 2 EDEM simulation of bending test under vertical, constant-rate deformation(Mortar spring distribution)

3 Simulation results



(a) Particle distribution (b) Mortar(pore) spring distribution

Fig. 3 3-D Collapse simulation of a concrete frame



(a) Particle distribution (b) Motar(Pore) spring distribution

Fig.4 3-D Collapse simulation of the three-storey frame

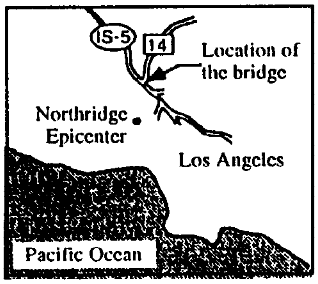


Fig. 5 Location of the bridge

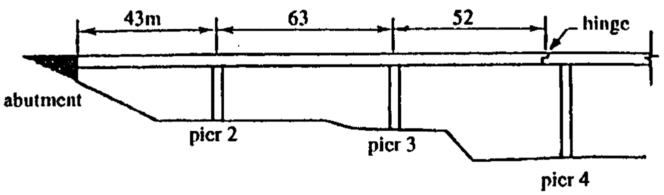


Fig. 6 Bridge SR14/I-5 South-end elevation

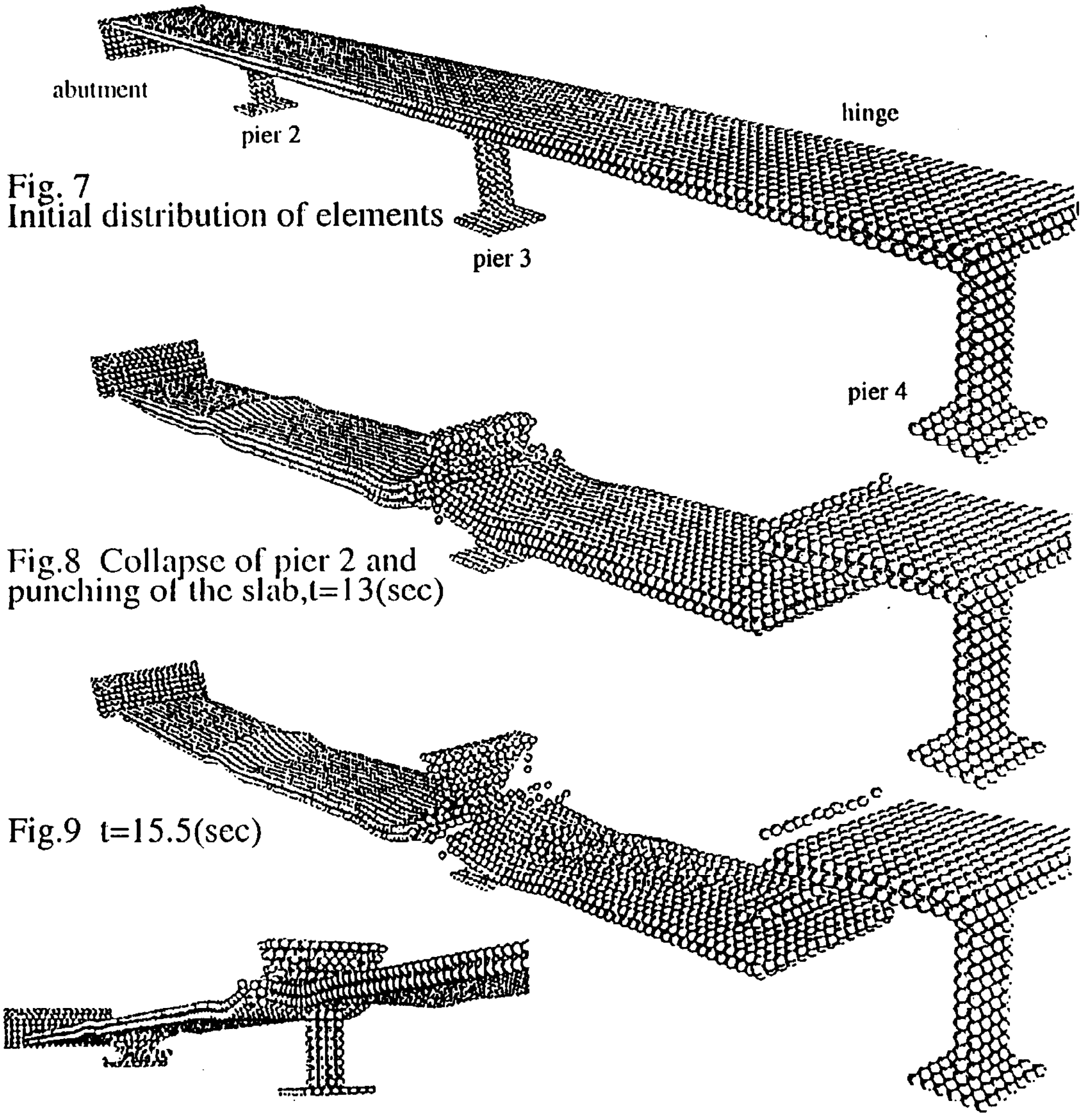


Fig. 7
Initial distribution of elements

Fig.8 Collapse of pier 2 and punching of the slab,t=13(sec)

Fig.9 t=15.5(sec)

Fig. 10 Crushing of pier 2, t=13(sec)

4 Conclusion

Models of concrete frames were designed based on the assumption that the concrete aggregate can be modeled as circular elements and that mortar that binds the aggregate can be represented by springs. The bending fracture of a beam was simulated. When dealing with problems involving fracture of a structure as a whole, such as a multistory frame in an earthquake, the number of elements becomes enormous when the aggregate is regarded as a single element in the model, and computation time becomes prohibitive. This difficulty was addressed by making the size of the element as large as possible while reducing the number of elements to a minimum. In consequence, the reinforcement of concrete cannot be directly accounted for, but by adopting equivalent values of pore-spring parameters for fracture criteria of reinforced concrete, the effect of reinforcement can be considered equivalently.

Although in some cases this approach does not accurately represent the mode of local fracture, the results for the fracture of a structure as a whole, generally replicate observed earthquake damage. The method at present has a number of imperfections and must be improved. We believe, however, that when the improvements are made, the EDEM will be a powerful means of analyzing the fracture of a structure.

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