I－A82 A NEW EFFICIENT TECHNIQUE FOR COLLAPSE ANALYSIS OF STRUCTURES

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1. Introduction

Although failure analysis of structures is very important for safety of people, current available methods for structural analysis cannot deal with this problem accurately. Methods based on assumption that the material is continuum, like the Finite Element Method (FEM), cannot perform the analysis up to collapse because limitations exist in representation of cracks and separation between elements. Although methods based on discrete element modeling of structures, like the Extended Distinct Element Method (EDEM), can follow the structural collapse behavior, it is less accurate than the FEM in small deformation range. The Applied Element Method (AEM) is a method for structural analysis that combines the advantages of both techniques. It can follow crack initiation, propagation and till failure of structures with high accuracy in reasonable CPU time[1]. In addition, the large deformation behavior and the rigid body motion of failed structural members can be followed accurately without additional complications[2]. Using the AEM, the structure medium is regarded as an assembly of distinct elements made by dividing the structure virtually. These elements are connected by distributed springs in both normal and tangential directions. In case of reinforced concrete, the reinforcement bars and concrete are modeled as continuos springs connecting elements together. Local failure of the elements is modeled by failure of springs connecting elements when the stress calculated from forces acting on springs exceeds the critical principal stress. The main objective of this paper is to show the wide range of applicability of the AEM to the collapse analysis of structures.

2. Representation of collision between elements

To consider the effects of collision, it is necessary to check the collision between elements during analysis. To simplify the contact condition, shape of the contacting edge of the element is assumed circle during collision as shown in **Fig. 1**. This means also that in the deformation range of recontact phenomenon, the edges of the members become round shape because of failure of sharp corners of the elements due to stress concentration. Every element has its space coordinates that depend on its location during analysis. These coordinates change during analysis especially after failure due to large geometrical changes in the structure. Using this technique, contact between elements is checked. To save CPU time, contact conditions between an element and its neighbor elements only, instead of all elements, are checked. When collision occurs, the time increment is reduced to follow the material behavior properly during collision. After separation of elements, the time increment is increased automatically by the program to its initial values. Collision springs, normal and shear springs, are added between the collide elements as shown in **Fig. 1**, and removed after separation of elements. The energy dissipation during collision process is represented by assuming increased stiffness "n*K" of collision springs when elements move away from each other (**Fig. 2**). The numerical technique is illustrated in Ref. (2).

3. Verification of the proposed technique

Three cases are introduced for verification. The first case is falling of a rigid element under its own weight and with different unloading stiffness factor (n). The element displacements are shown in **Fig. 3**. The obtained element displacements and velocities agree well with the theoretical values. In addition, the difference between the obtained and theoretical times of contact between the element and the ground was less that 1% for all contacts till the element stops. The second case is falling of a block consists of 100 elements. The variation of energy components during analysis is verified. The unloading stiffness factor adopted is "2", which means that the half of the total energy is dissipated during each contact. **Figure 4** shows the changes of kinetic energy and potential energy during analysis. The last verification example is a collapse process of an RC frame attacked by falling rock. The dimension of the frame and reinforcement detail are shown in **Fig. 5**. The reinforcement detail is not symmetry. The collapse process of the frame and the rock, shown in **Fig. 6**, are summarized as follows; After 1.019 second, the falling block attacks the frame. Bending cracks appear first in the middle of the beam and the next, they appear at the connections. The falling block is cracked in the middle because of high collision forces followed by cut of the reinforcement at the middle of the beam and at connections. The beam is divided into two main falling parts moving as rigid bodies. The total behavior of the structure could be simulated even after collision between the rock and beam and between the rock or failed members and the ground.

Key words: large deformation, rigid body motion, Applied Element Method, collision, collapse, computer simulation
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4. Conclusions

A newly developed model, AEM, is introduced. It is proved that collapse behavior of structures can be followed accurately without any complications. It is almost impossible to perform such kind of analysis using the conventional structural simulation models, such as FEM, where separation and new contact between elements are very difficult. Moreover, the time increment adopted in the analysis can be much larger than the DEM because of the use of global stiffness matrix.

References

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2. Meguro K. and Tagel-Din H.: A new simple and accurate technique for failure analysis of structures, Bulletin of Earthquake Resistant Structure, No. 31, 1997.

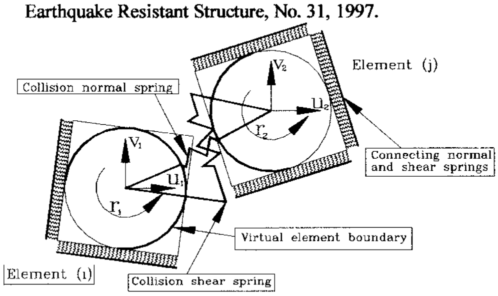

Fig. 1 Elements in collision process

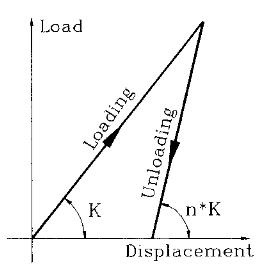

Fig. 2 Load-displacement relation of a contact spring in loading and unloading condition

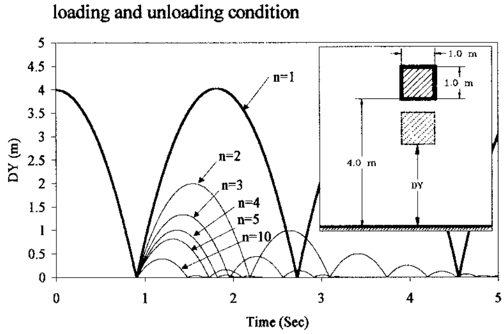

Fig. 3 Time history of displacement of a falling element under its own weight with different unloading stiffness factors "n"

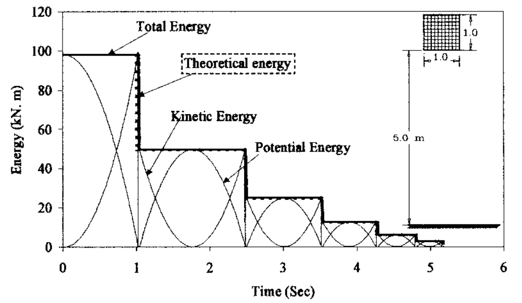

Fig. 4 Changes of kinetic energy, potential energy and total energy with time for a falling block composed of 100 elements under its own weight "Unloading stiffness factor, n=2"

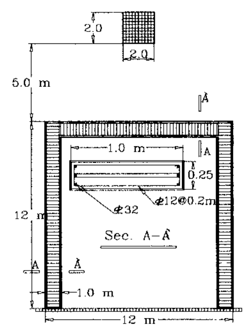

Fig. 5 Shape, dimension and reinforcement details of an RC frame and a falling block

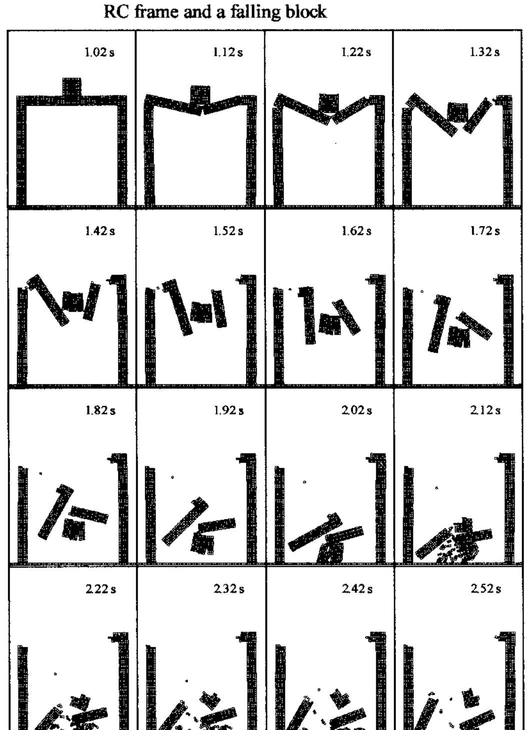

Fig. 6 Failure process of an RC frame attacked by a falling block