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APPLICATION OF THE EXTENDED DISTINCT ELEMENT METHOD FOR COLLAPSE SIMULATION OF A DOUBLE-DECK BRIDGE

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The Distinct Element Method (DEM), in which soil is represented as an assembly of numerous discrete particles, does not account for the continuity of the medium. The extended method has another physical structure which represents the effect of the internal material between the particles as mortar of concrete. We simulated the two-dimensional dynamic fracture process of the Cypress Double-Deck Bridge on Interstate 880-Line suffered by the 1989 Loma Prieta earthquake using this method. Results agree well with the real damage qualitatively and confirmed that this method can simulate the collapse of structures involving discontinuous behavior.

Key Words : *distinct element method, extended (or modified) distinct element method, fracture analysis, earthquake damage, computer simulation*

1. INTRODUCTION

A number of earthquakes in the past entailed heavy casualties. To prevent such mishaps, and assure the general public safety in the event of future earthquakes, it is vital to analyze how structures would collapse. An attempt of analyzing the process which structures behaviorally follow in their collapses, namely, "Where and how they undergo collapse?", "How long is the time of collapse, short or long?", "How far would the fragments of structural members fly in the process of collapse?", and "How wide would be the scope of collapse which structures might possibly experience, partial or overall collapse?", is expected to cut our technological inquisitive way through the domain of structure collapse behavioral uncertainties. If the intensive light of engineering concerned with structural collapse is projected upon these uncertainties, there will be brought forth some approaches to clarify them. For example, we may undertake such architectural designs which allow partial structural collapse but prevent complete collapse. The means for such an analysis at the present stage is the method which Iwashita and Hakuno1) have extended from the distinct element method due to Cundall2).

First, we applied the extended distinct element method, abbreviated as EDEM, for the bending test of a concrete beam without reinforcement. Next, we simulated the collapse process of the Cypress Double-Deck Bridge on Interstate 880-Line which incurred damage on the occasion of 1989 Loma Prieta earthquake. The consequences of the analysis which we recently undertook give a good qualitative account for the phenomena which structures exhibit in their actual collapses.

2. EXTENDED DISTINCT ELEMENT METHOD

To date, the extended distinct element method used to be applied as a means to analyze the behaviors (including the liquefaction phenomenon) of soil and bedrocks. In the field where such analyses have so far been carried out, this method is of late getting highly appreciated for its applicability for such behavioral analyses1)~9).

With reference to the subject method, Iwashita and Hakuno attempted their theoretical development with the pore material's (clay between sand particles, for example) behavioral effect substituted by the function of a spring, wherein they called this spring as a pore-spring. The concept of this pore-spring is understood to account for two mechanisms; (a) mechanism of the pore material's behavioral effect, and (b) the soil grain deformation restricting effect. The latter effect is due to the shape (polygon) of the grains which, in general, are not round. The sharp corners restrict the deformation of the grains in contrast to the behavior of circular grains.

With pore materials taken as cement mortar in the case with concrete7), and coarse aggregates likewise regarded as round elements (**Fig.1**), we implemented the simulation of a bending test of small reinforcement-free concrete beams. Via the simulation, it was found that the mode of EDEM modeling with coarse aggregates regarded as round

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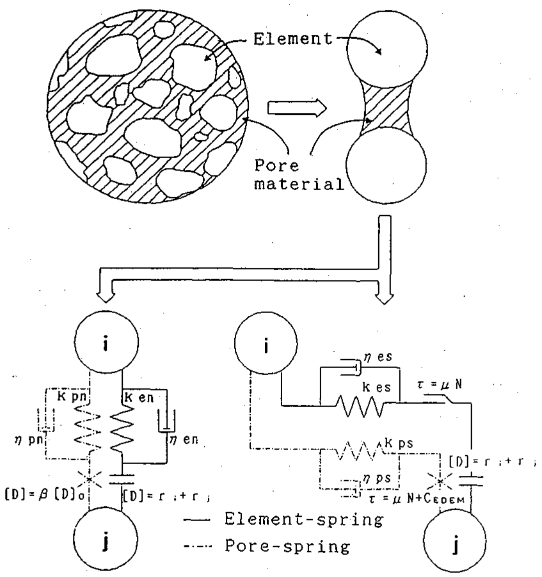


(a) Normal Direction (b) Tangential Direction

Fig.1 EDEM modeling of concrete

elements requires handling of an enormous number of elements to analyze the mechanism of entire structural collapse. Taking this into account, we came to a conclusion that apart from the discussion of methodological feasibility in the future, such a modal approach would be impractical with current computers undergoing operational capability limits. It was further clarified that both the fundamental vibration modal and collapse modal analyses which carry significance in respect of engineering, need no necessity of the EDEM modeling at a material level involving too many elements. Our main purpose is to simulate the collapse behavior of the whole structure rather than knowing the local behavior at micro level. Therefore, in an attempt to simulate the collapse mechanism of a double-deck bridge when exposed to an earthquake, the elements involved were decreased as much as possible, with at least two elements arranged widthwise of each bridge pier and girder (these structural members are essential for the transmission of bending moments).

For an element, i, (with a mass of m_i, and an inertia moment, I_i) of the EDEM model, the equations of motion are

$$m_i\ddot{u}+C_i\dot{u}+F_i=0 \quad \cdots\cdots(1)$$

$$I_i\ddot{\phi}+D_i\dot{\phi}+M_i=0 \quad \cdots\cdots(2)$$

where

F_i is the resultant of forces acting on the element,
M_i is composite moment acting on the element,
C_i and D_i are the respective damping coefficients,
u and ϕ are displacement vector and rotation of the element.

Both displacement vector u and rotational displacement ϕ are obtained by a step-by-step time integration of equations (1) and (2).

Details regarding the criteria of the establishment and fracture of pore-springs are given in ref.7). Pore-springs are set when the distance between two elements are smaller than a specified value. A critical tensile strain is used as fracture criterion in the normal direction, and in the tangential direction, Mohr-Coulomb's fracture criterion is adopted.

3. ESTIMATION OF PARAMETERS FOR THE EDEM

The spring constants of each element-spring and pore-spring are decided, depending on the wave propagation velocity through a medium. More precisely, each of these spring constants is set in a manner that the velocity of wave propagation through a model medium will agree with that of the medium to be analyzed. The wave propagation velocities, V_p and V_s, are first calculated according to Young's modulus, Poisson's ratio, and density of the medium concerned. Assuming that V_p and V_s are related with the normal directional spring constant, and the tangent directional spring constant, respectively, a composite spring constant in each direction (element- and pore-springs, respectively) is subsequently calculated. Thereafter, the respective directional spring constants of each element- and pore-springs are calculated.

The procedure for estimating parameters takes into account the velocity of wave propagation through a model which approximates closely to that through the medium, and thereby enables to fabricate such a model having the physical properties matching those of the medium concerned.

Furthermore, the model is given shocks, whereby elastic waves are propagated through it for the simulation as shown in **Fig.2**, and subsequently, following the simulation results, the velocity of elastic wave propagation through the model is calculated. In the event that the difference between the calculated elastic wave propagation velocity and the actual propagation velocity is found large, the respective spring constants are adjusted. **Fig.2** is an example of wave propagation analysis of a very soft ground model. Compressional wave velocity, V_p, obtained from the simulation is about 85 m/s which agrees well with that obtained from Young's modulus, Poisson's ratio, and density of the ground considered.

The above procedure is for the estimation of spring constants of the media, such as isotropic

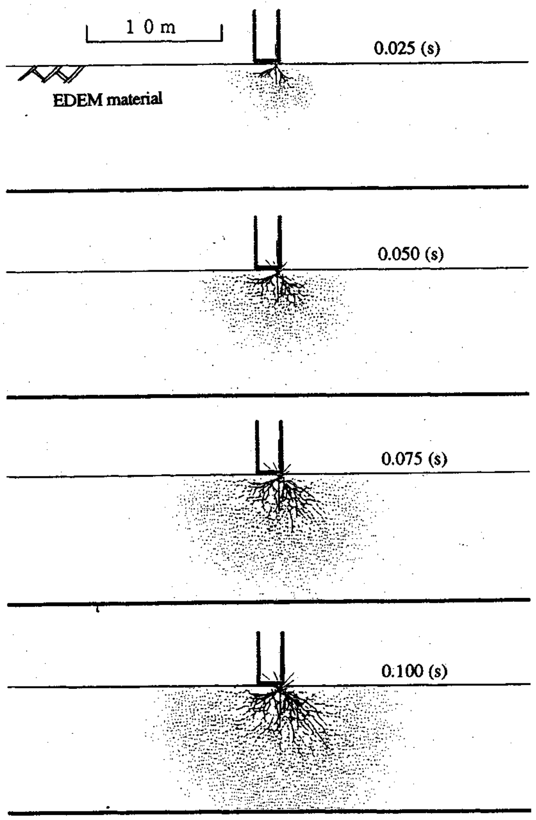
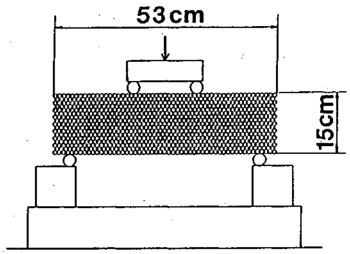


Fig.2 Wave propagation through a EDEM material (Normal force distribution)

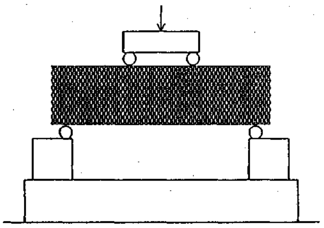
ground or concrete without reinforcement. When the medium is anisotropic, (for example, reinforced concrete, which is composed of different materials like concrete and reinforcement), we should take different parameters for each (ref. 7). When we use a model with fewer elements like that in section 4.2 for the analysis of a double-deck bridge, we have to consider the overall behavior of the structure as well. In such a case, the behavior of the model is compared with that of the real structure of the same geometry, for example, by conducting sweeptest of the model with the EDEM. The damping coefficients used in this analysis have values commonly used in seismic response analysis.

4. RESULTS OF NUMERICAL SIMULATION

Although the main purpose of this study is to simulate the fracture process of the double-deck bridge which suffered damage due to the 1989 Loma Prieta earthquake, we first simulated the bending test of a concrete specimen model in which each gravel is represented by one element. This is an example of material level modeling. From the result of this test, one can clearly understand the difference between the material level modeling and macro modeling that is adopted for the collapse simulation of the double-deck bridge in this study.



(a) Particle distribution



(b) Mortar-Spring distribution

Fig.3 Model of concrete specimen (Bending test model)

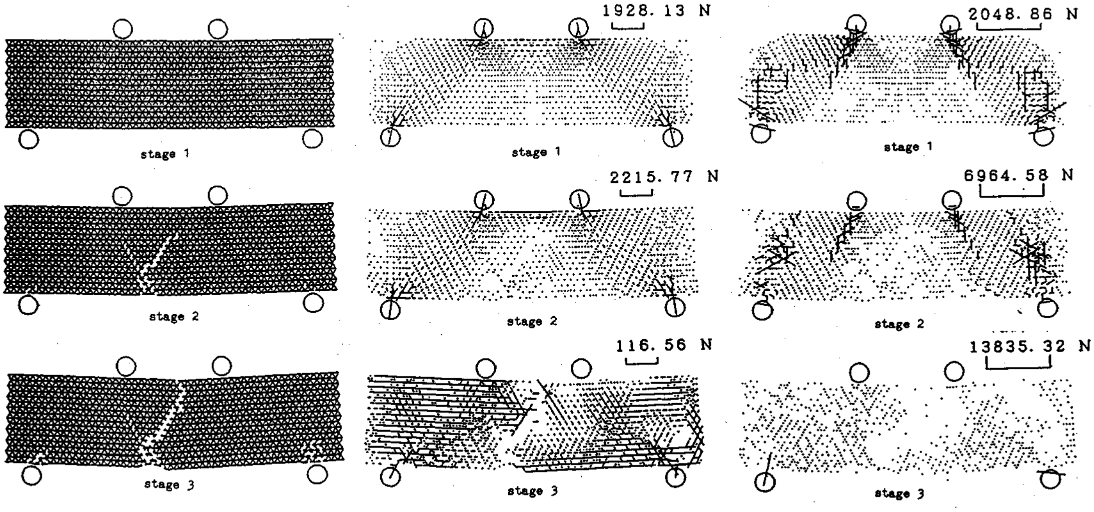
(1) Bending test of concrete specimen

We attempted simulating a bending collapse test of a concrete specimen according to the EDEM, using the model presented in **Fig.3**. The loading force to the concrete specimen is applied by downward relocation of two points at the upper part of the specimen via displacement control, as shown in **Fig.3**. Presented in **Fig.3**(a) is the particle distribution of 893 round elements, each with a diameter of 1.0 cm, showing the locations of respective coarse aggregates. Meanwhile, **Fig.3**(b) gives the distribution of pore-springs at the initial stage. The parameters employed for the bending collapse test are as specified in **Table 1**.

Test results are shown in **Fig.4**. Taking a look at the mortar-spring distribution in **Fig.4**(a), it is observed that the model is not subjected to cracking at stage 1. Referring to **Figs.4**(b) and (c), it is found that large compressive force and shearing force are present on the line which runs through four loading points inside the specimen, and also that the specimen has undergone tensile strain originated cracking at stage 2, with the upper part remaining free from cracking. It is further clarified that in the neighborhood of a cracking inflicted part, both tensile force and shearing force are approximately zero at stage 2, with the neighborhood area relieved of stress. It is likewise witnessed that the supporting points at both ends of the specimen have experienced slight collapse.

Table 1 Parameters of the simulation (Bending test model, see Fig.4)

Element-Spring (Normal)	Spring constant, Ken(N/m)	6.0×10^6	Element-Spring (Tangential)	Spring constant, Kes(N/m)	3.0×10^6
	Damping coefficient, ηen(Ns/m)	1.5×10^5		Damping coefficient, ηes(Ns/m)	1.0×10^3
Pore-Spring (Normal)	Spring constant, Kpn(N/m)	3.0×16^6	Pore-Spring (Tangential)	Spring constant, Kps(N/m)	1.5×10^6
	Damping coefficient, ηpn(Ns/m)	0.0		Damping coefficient, ηps(Ns/m)	0.0
Setting distance ratio of pore-spring, α		1.05	Critical tensile strain of pore-springs, β		1.01
Density of element, ρ (Kg/m^3)		2.5×10^3	Cohesion, C_{EDEM} (N)		1.0×10^4
Friction coefficient, μ		1.00	Time increment, Δ t (s)		1.0×10^{-5}
Loading rate, V_L (cm/s)		2.0			



(a) Mortar-Spring distribution (b) Compressive normal force distribution (c) Shear force distribution

Fig.4 Simulation of a bending test under vertical, constant-rate deformation

Notwithstanding the fact that the specimen configuration as well as the loading points and fulcrums arranged for the test are symmetrical, the distribution of cracks present within the specimen is unsymmetrical. The above observation may possibly be due to the unsymmetrical position of the origin of coordinates. It must be noted that the cumulative calculations were carried out with the origin of coordinates set at a leftward point and not the center within the specimen. Therefore, the coordinates of respective elements are unsymmetrical, and as a consequence, the incremental displacement, if any, is as small as an extremely short time interval during calculations, such that displacement increments sometimes cannot be added to the original coordinates of respective elements due to underflow. In such a case, if there exists as much error as one digit in the coordinates of a certain object located at a point corresponding to the origin of the coordinates, the underflow of those elements, which are through with some coordinate extension, goes with as much error as one digit. It is considered that the displacements taking place with the stresses of individual elements are thus deprived of symmetry.

Stage 3 coincides with a tensile strain stemmed crack transversely running through the specimen, with some pore-springs in a certain part of the specimen remaining unbroken. But in this stage, it may be supposed that the specimen would have broken into two parts. The distributions of normal force and shear force in **Figs.**4(b) and (c) clearly reveal this fact.

One reason for conducting the bending test of a concrete specimen without reinforcement, which is not used as a structural member in Japan, is that even now, seismic damage of non-reinforced old structures are sometimes observed in the Middle East, Central Asia, and Central and Southern America.

(2) Collapse process simulation of a double-deck bridge suffered from the 1989 Loma Prieta earthquake

The extended distinct element method (EDEM) is a conceptual model realized with a unique idea incorporated, wherein elements are each recognized as a unitary element of motion, a key to solve the equation of motion, and an interaction among elements is regarded as a spring action in a broad sense. In another aspect, the EDEM is otherwise taken hold of as a lumped mass system, a subsystem of the composite, multi-degree-of-freedom (MDOF) system. Reference will now be made to "What is the most outstanding difference between the lumped mass system branched off from the MDOF system which is generally applied as a means for the dynamic response analysis, and the EDEM system?" The difference lies between the respective system configurations, the former being characterized in that only continuous bodies can be analyzed while the latter, featuring its configuration, enables behavioral tracking over such a scope from a continuous body to a discontinuous body. Taking note of this system configuration, the EDEM system may be grasped as a means for the response analysis (extended MDOF) following the multi-degree-of-freedom system characterized by an extended scope of application.

Depending upon the material characteristics of the medium concerned and the scales of the structures to be modeled by the EDEM, it is impractical and beyond the operational capability of present computers to have models in which the elements have one-to-one correspondence with those in the real medium. In the case where basic vibration and subsequent collapse modal particulars, for example, are required to be clarified, both of which hold significance in engineering, there is no need to model at the material level involving a large number of elements. In such a case, it is useful to consider the EDEM as an extended MDOF system, which can be applied to the collapse behavior of structure.

The conventional MDOF system dynamic response analysis finds it very difficult to analyze the dynamic behavior in the stage of structural collapse initiation or in the process wherein structural collapse is progressing. However, the dynamic response analysis following the EDEM system allows us to simulate the collapse behavior of structures from a sound state to complete collapse. Therefore, with the EDEM system dynamic response analysis, the structural vibration characteristics which are variable with the outbreak of collapse, and in keeping pace with the progress of collapse can phenomenalistically be illustrated in a state of spontaneity.

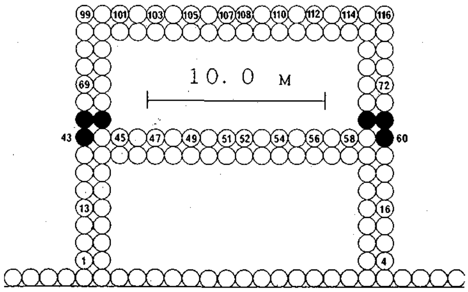


Fig.5 Model of the Cypress Double-Deck Bridge on Interstate 880-Line (Pore-springs set between shaded elements are much weaker than others)

Table 2 Particle data of a double-deck bridge model (see Fig.5)

		Height × Width (X m × Z m)	18.0×15.0
Element radius (cm)	50.0	Total number of elements	116

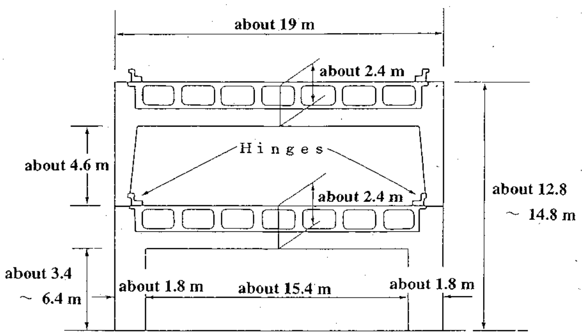
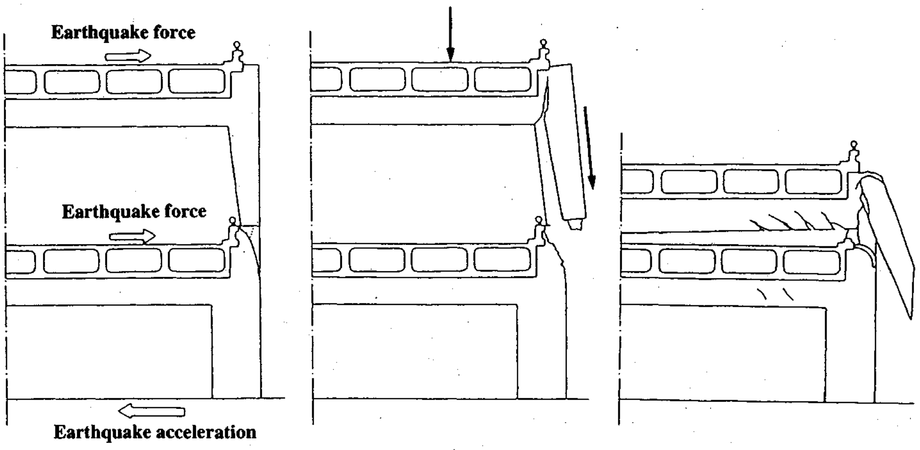


Fig.6 Typical cross section of the Cypress Double-Deck Bridge on Interstate 880-Line10)

In this study, accepting the EDEM system as an extended MDOF system, we attempted the simulation of collapse which a double-deck bridge had suffered in the 1989 Loma Prieta earthquake.

a) Model for simulation

Using the model shown in **Fig.5** (see **Table 2** for the particulars of element data), we conducted a simulative analysis not only of the responses which

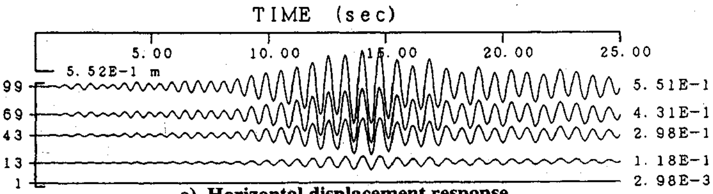


(a) (b) (c)

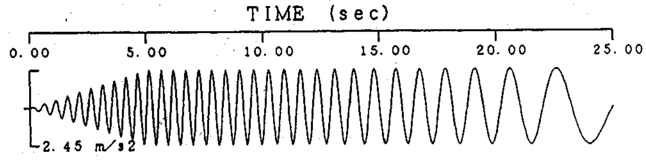
Fig.7 Fracture mechanism of the Cypress Bridge on Interstate 880-Line[10]

Table 3 Parameters of the simulation (Sweeptest of a double-deck bridge, see Fig.8)

Element-Spring (Normal)	Spring constant, Ken(N/m)	4.5×10^9	Element-Spring (Tangential)	Spring constant, Kes(N/m)	1.5×10^9
	Damping coefficient, ηen(Ns/m)	1.38×10^5		Damping coefficient, ηes(Ns/m)	8.0×10^4
Pore-Spring (Normal)	Spring constant, Kpn(N/m)	4.5×16^6	Pore-Spring (Tangential)	Spring constant, Kps(N/m)	1.5×10^8
	Damping coefficient, ηpn(Ns/m)	1.0×10^4		Damping coefficient, ηps(Ns/m)	7.0×10^3
Setting distance ratio of pore-spring, α		1.45	Critical tensile strain of pore-springs, β		1.10
Density of element, ρ (Kg/m^3) [Deck part]		2.5×10^3 [1.0×10^3]	Cohesion, C_{EDEM} (N)		1.0×10^7
Friction coefficient, μ		1.00	Time increment, Δ t (s)		5.0×10^{-5}
Yield compressive force of element- spring, Fmax (N)		6.0×10^{10}			



a) Horizontal displacement response



b) Input wave for sweeptest

Fig.8 Result of sweeptest using bridge model

Table 4 Parameters of the simulation (Fracture analysis of a double-deck bridge due to seismic loading, see Fig. 10)

Element-Spring (Normal)	Spring constant, Ken(N/m)	4.5×10^9	Element-Spring (Tangential)	Spring constant, Kes(N/m)	1.5×10^9
	Damping coefficient, ηen(Ns/m)	6.0×10^4		Damping coefficient, ηes(Ns/m)	3.45×10^4
Pore-Spring (Normal)	Spring constant, Kpn(N/m)	4.5×16^8	Pore-Spring (Tangential)	Spring constant, Kps(N/m)	1.5×10^8
	Damping coefficient, ηpn(Ns/m)	2.0×10^4		Damping coefficient, ηps(Ns/m)	1.1×10^4
Setting distance ratio of pore-spring, α		1.45	Critical tensile strain of pore-springs, β [Shaded elements]		1.05 [1.0004]
Density of element, ρ (Kg/m^3) [Deck part]		2.5×10^3 [1.0×10^3]	Cohesion, C_{EDEM} (N) [Shaded elements]		1.0×10^7 [1.0×10^5]
Friction coefficient, μ		1.00	Time increment, Δt (s)		5.0×10^{-5}
Yield compressive force of element- spring, Fmax (N)		6.0×10^5			

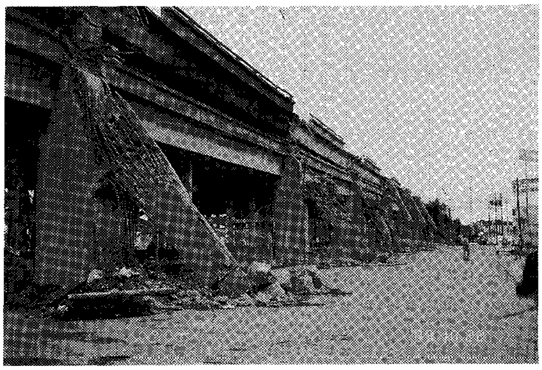


Photo.1 Collapse of the Cypress Double-Deck Bridge on Interstate 880-Line

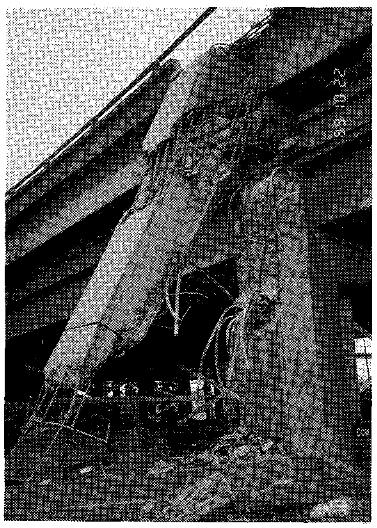


Photo.2 Collapse of the Cypress Double-Deck Bridge on the opposite side of Photo.1

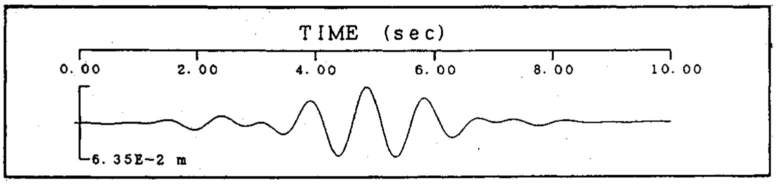
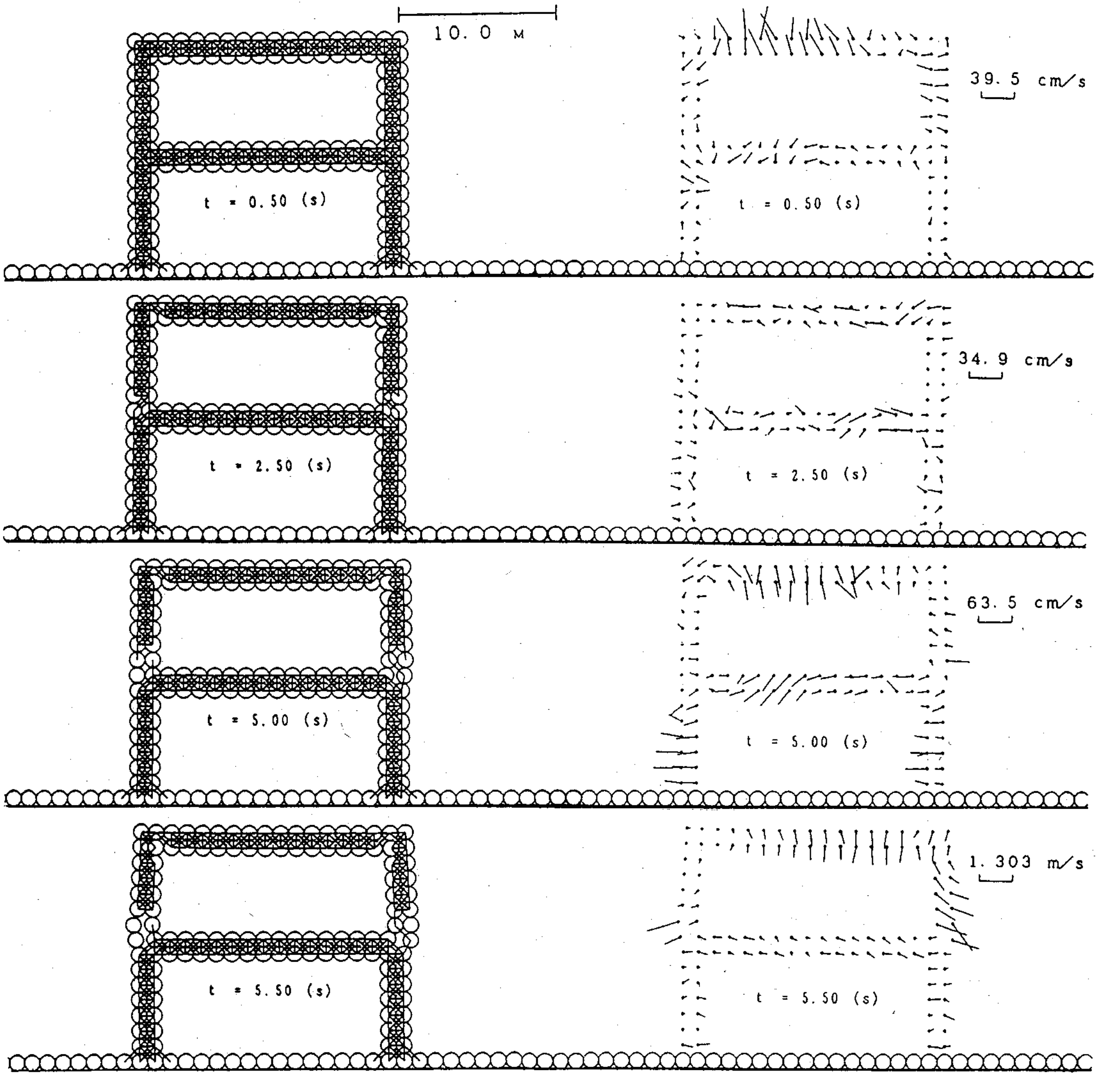


Fig.9 Input wave for fracture analysis of a double-deck bridge

a 2-story structure exhibited when applied with the external force of an earthquake, but also of the process of collapse thereof. The numbers in the above figure are respective element numbers selected for use in plotting the responses witnessed from the model under the simulative analysis while exposed to earthquake-initiated vibrations. This model was patterned after the Cypress Bridge on the Interstate 880-Line which suffered heavy damage during the 1989 Loma Prieta earthquake. Presented in **Fig.6** are the typical cross section of the bridge, and the pier type. **Fig.7** shows the mechanism of collapse estimated for the bridge based on the report from a Tokyo Metropolitan



(a) Distribution of elements and pore-springs (b) Velocity distribution

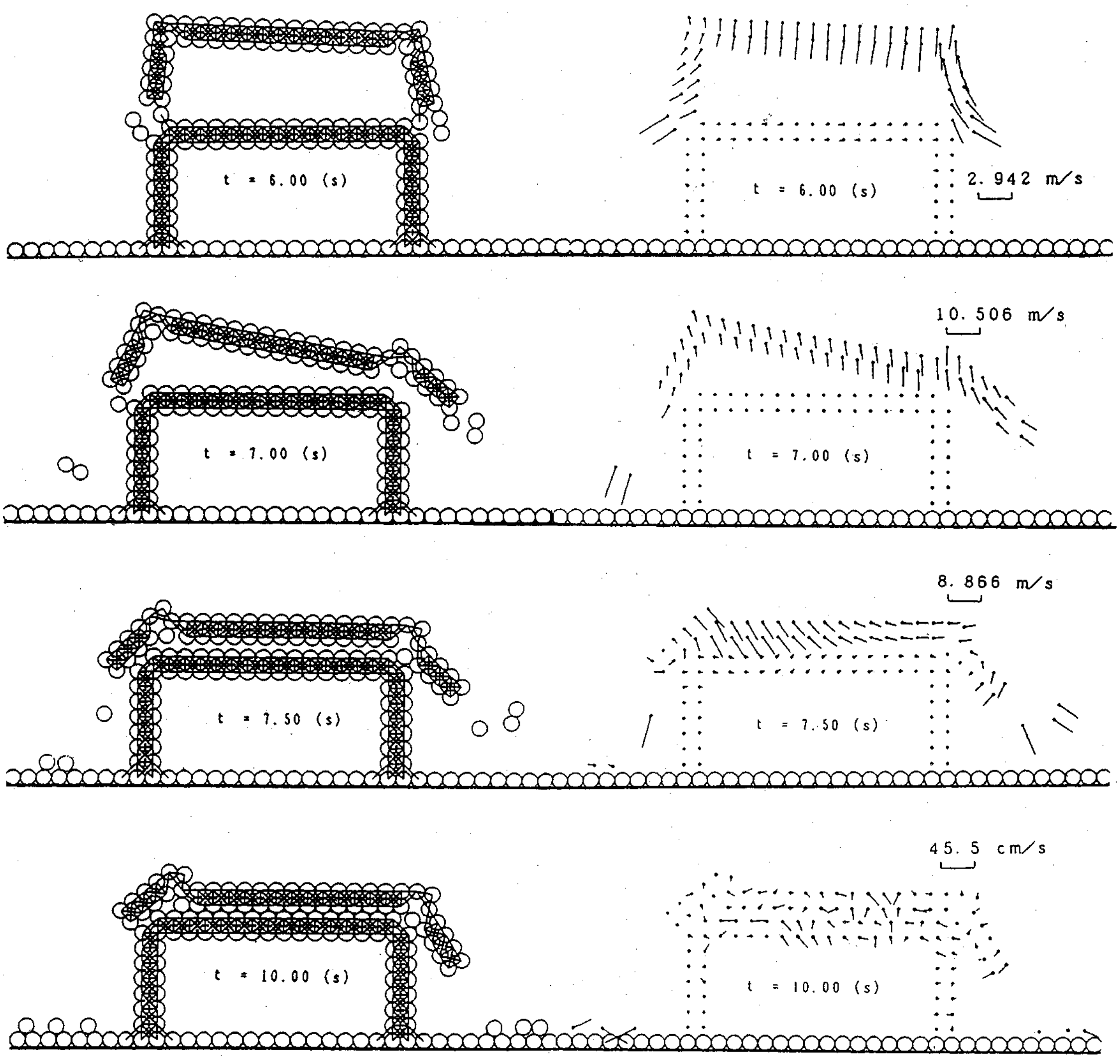
Fig.10 Fracture process of a double-deck bridge due to seismic loading

Loma Prieta Earthquake Survey Team[10].

b) Sweeptest

To examine the vibration characteristics of the model for the simulative analysis, we implemented the simulation of a sweeptest with the acceleration (specified in **Fig.8**) applied to the model. The parameters used for this simulative analysis are given in **Table 3**.

During the sweeptest, resonance of the model may take place. In such case, very large loads are applied to the structural model. Thus the displacement response becomes very large. When such big loads and displacements applied to the model destroy it, we cannot obtain linear dynamic behavior. Thus, we adopted very large Fmax and β which are the yield value of the force acting on element-springs in the normal direction and the tensile strain parameter for pore-springs in order not to have collapse even if there is a resonance during the sweeptest simulation. **Fig.8** shows the findings from the analysis. Though the investigation with the EDEM system used for the dynamic response analysis in the same applicative understanding as with the lumped mass system from the conventional MDOF system has hardly been undertaken in the past, noting the consequences of the simulative analysis, it is found that use of the EDEM system enables the implementation of the dynamic response analysis of structures, similar to the case of the conventional MDOF system.



(a) Distribution of elements and pore-springs (b) Velocity distribution

Fig.11 Fracture process of a double-deck bridge due to seismic loading

Examining the results of the analysis drew the finding that the primary natural period of this model was around 0.8 s. Although this natural period seemed longer, compared with Cypress Bridge, the model was applied to the qualitative simulation analysis.

c) Fracture analysis with earthquake-initiated vibrations

Following a primary natural period finding with the model via the sweeptest, we carried out an earthquake response analysis for the case wherein the model was exposed to earthquake force, with an earthquake-initiated vibration generator applied which had been fabricated to produce the vibrations including the frequency components corresponding to the natural and a little bit longer than the natural period of the model. The conventional earthquake response analysis using the lumped mass system or a finite element method (FEM) can be useful to the limit where structural members yield to earthquake-initiated force, whereby such a model analysis fails to undertake analyzing the process of earthquake-caused structural collapse. Meanwhile, the EDEM system applied earthquake response analysis renders the capability of demonstrating in a state of spontaneity, the nonlinear structural behaviors involving the decline of rigidity in keeping pace with the occurrence of a crack or along the progress of cracking, and the changes in structural vibration characteristics.

In undertaking this study, we implemented a pier structural collapse simulation analysis, using the parameters given in **Table 4** upon preparing a model of the pier in **Fig.5**. This bridge structure can be considered to have hinged ends at the bottom in the upper deck (**Fig.6**). Therefore, in the corresponding model (**Fig.5**), the fracture criteria of pore-springs (β and C_{EDEM}) are very much lowered for the elements shaded to take into account the effect of the hinges.

The outcomes of analysis are presented in **Figs.10** and **11.** Taking a look at the figures, it is found that a shear crack first emerged at a part where each upper deck column is fitted, due to stress concentration, and a joint where the upper deck girder and the column are coupled together went into collapse subsequently. Further, it was clarified that the external application of earthquake-initiated force to the model entailed the collapse of the above-mentioned upper deck column fitted part, with an upper deck column getting dislocated from a lower deck column, and then laterally falling down outward. It was likewise witnessed that thereafter, the upper deck fell over the lower deck in a manner that the former might overlay the latter. **Photos 1** and **2** commonly show not only the damage which Cypress Bridge on Interstate 880-Line incurred due to the 1989 Loma Prieta earthquake but also good coincidence with the model over the mode of collapse.

Comparing the mechanism of collapse (**Fig.7**) and the damage in **Photos 1** and **2** with the findings from the structural collapse simulation analysis draws a supposition that Cypress Bridge might possibly have undergone earthquake damage with collapse process and mechanism as confirmed in the simulation analysis.

5. CONCLUSION

We applied the EDEM to both bending fracture test of concrete specimen and collapse simulation of a double-deck bridge (Cypress Bridge on Interstate 880-Line) damaged due to the 1989 Loma Prieta earthquake. In case of the bending test, the specimen was modeled at material level using many small elements, in a manner wherein aggregates are reckoned as respective elements. While in the collapse simulation of a double-deck bridge, the EDEM was used as an extended MDOF system reflecting that the total number of elements was reduced to shorten the CPU time.

Results obtained in the study qualitatively agree well with past real experiment results and seismic damage. Using two level modeling, we can follow the fracture process of a medium at material level, and of the whole structure. The level of modeling will depend on the purpose of the simulation.

Examining the simulation results drew a conclusion that the macro model of the double-deck bridge would be capable of demonstrating to some extent how a structure would undergo local collapse (shear fracture, for example), whereby the model would be allowed to account for the process or the mechanism of actual earthquake-caused structural collapses with certain accuracy. Though it is considered that the EDEM system is required to go through improvements over various points, we believe that the subject system will be serviceable in the future as an effective means to analyze the mechanism of structural collapses.

REFERENCES

1) Iwashita, K. and Hakuno, M.: Modified Distinct Element Simulation of Dynamic Cliff Collapse, Structural Eng./ Earthquake Eng., Japan Society of Civil Engineers (JSCE), Vol.7, No.1, pp.133 s～142 s, 1990.
2) Cundall, P.A.: A Computer Model for Simulating Progressive, Large Scale Movement in Blocky Rock Systems, Symp. ISRM, Nancy, France, Proc., Vol.2, pp.129～136, 1971.
3) Cundall, P.A. and Strack, O.D.L.: A Discrete Numerical Model for Granular Assemblies, Geotechnique, Vol.2, No.1, pp.47～65, 1979.
4) Kiyama, H. and Fujimura, H.: Study on the Gravity Flow of Rock Granular Assembly, Proc. of JSCE, 322, pp.101～110, 1982. (in Japanese)
5) Kiyama, H. and Fujimura, H.: Analysis of the Gravity Flow of Rock Granular Assembly by Cundall Model, Proc. of JSCE, 333, pp.137～146, 1983. (in Japanese)
6) Uemura, D. and Hakuno, M.: Granular Assemby Simulation with Cundall's Model for the Dynamic Collapse of the Structural Foundation, Structural Eng./Earthquake Eng. (JSCE), Vol.4, No.34, pp.155 s～164 s, 1987.
7) Meguro, K. and Hakuno, M.: Fracture Analyses of Concrete Structures by the Modified Distinct Element Method, Structural Eng./Earthquake Eng. (JSCE), Vol.6, No.2, pp.283 s～294 s, 1989.
8) Uchida, Y. and Hakuno, M.: Distinct Element Analysis of Dry Rock Avalanches, Structural Eng./Earthquake Eng. (JSCE), Vol.7, No.2, pp.203 s～214 s, 1990.
9) Meguro, K., Iwashita, K. and Hakuno, M.: Fracture Analyses of Media Composed of Irregularly Shaped Regions by the Extended Distinct Element Method, Structural Eng./Earthquake Eng. (JSCE), Vol.8, No.3, pp.131 s～142 s, 1991.
10) Tokyo Metroporitan Loma Prieta Earthquake Survey Team: Someday in Tokyo, Report on the Damage of 1989 Loma Prieta Earthquake, 1990. (in Japanese)

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拡張個別要素法による2層高架橋の崩壊シミュレーション

目黒公郎・伯野元彦

本研究では，連続体から完全非連続体まで解析可能な拡張個別要素法（EDEM）を用いて，コンクリート供試体の曲げ破壊試験と，1989年のロマ・プリータ地震で被害を受けたサイプレス高架橋の崩壊シミュレーションを行った．前者は，粗骨材をEDEMモデルの1要素に対応させる媒質レベルのモデル化による解析例であり，粗骨材間のモルタルの破壊メカニズムなどの微視的な破壊現象を解析するものである．一方後者は，EDEMを拡張型の多自由度応答解析法（Extended MDOF）と位置付けた解析であり，構造物全体の破壊解析を目的とするものである．解析結果は，実際の破壊試験結果・地震被害と定性的によく一致した．定量的な精度の問題など解決すべき課題はあるが，解析目的に応じてモデル化のレベルを適切に選択することによって，ミクロ（媒質レベル）からマクロ（構造物全体）までの破壊現象がEDEMを用いて解析できることがわかった．