APPLICATION OF THE DISCRETE FINITE ELEMENT METHOD TO SEISMIC ANALYSIS OF MASONRY STRUCTURES

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Introduction: Most of historical structures remaining from various civilizations such as Egyptian, Roman, Pertian, Hittite and Turkish etc. are masonry structures consisting of distinct blocks. They are still commonly practiced in many countries all over the world. In this paper, the applicability of the Discrete Finite Element Method (DFEM) to seismic analysis of masonry structures are checked and discussed.

Discrete Finite Element Method (DFEM): Recently, authors has proposed a technique, called DFEM, based on the finite element method together with the contact element to model structures consisting of blocks of arbitrary shapes (Mamaghani 1993, Mamaghani et al. 1994, 1997). The proposed DFEM considers deformable blocks as sub-domains and represent them by solid elements. The block interaction, such as sliding or separation, is modeled with the contact elements which are far-superior to the joint or interface elements. This method can handle with large block motions within the framework of the finite element method.

The DFEM was used to simulate behavior of masonry engineering structures, such as, stability of a single block or a pile of blocks on an incline, arch structures and masonry dams neglecting the inertia term in the authors previous work (Mamaghani et al. 1994, 1997). Some of the results have been compared with those obtained from other techniques. It has been shown that the proposed approach is very promising to analyze the stability of masonry structures under static loads.

The present paper is concerned with several applications of the DFEM to seismic analysis of masonry structures. A visco-elastic constitutive law for linear behavior of blocks and a visco-elasto-plastic constitutive law for non-linear behavior of contacts together with updated Lagrangian scheme are used in the analysis (Mamaghani 1993). Specifically, towers, walls, dams, arches of masonry type are analyzed and the applicability of the DFEM to seismic analysis of such structures are checked and discussed.

Numerical results and discussions: In this section, some typical numerical results will be presented and evaluated. In all examples, the foundation of the structures was subjected to lateral acceleration as shown in Figure 1. The material and mechanical properties of blocks, foundations and contacts are given in Table 1, where λ and μ denote Lame's constants, and γ, E_n, G_s, h and ϕ indicate unit weight of rock mass, elastic modulus, shear modulus, band width of contact elements and friction angle, respectively. The time step was chosen as 0.2 second.

Table 1. Material Properties of Rock Blocks and Contacts

Rock Blocks					Contacts					
λ MPa	μ MPa	λ^* $MPa.s$	μ^* $MPa.s$	γ kN/m^3	E_n MPa	G_s MPa	E_n^* $MPa.s$	E_s^* $MPa.s$	h (mm)	ϕ $(^\circ)$
30	30	30	30	25	5	2.5	5	2.5	5	35

Figures 2, 3 and 4 show the initial and deformed configurations of a masonry tower, a masonry wall, and a masonry arch structure, respectively, at the time step of 50 (10 second) and responses of a nodal point at the top of the structures with time. As seen from Figure 2, the response of the tower is quite similar to those observed in actual earthquakes. It is worth nothing that the tower is stable at the end of shaking. However, it does not return to its original position due to sliding along block contacts caused by the imposed form of the acceleration waves. Figure 3 shows that there is a relative sliding at the base of the wall, while blocks are seperated and rotated within the wall. As expected, the wall also does not return to its original position at the end of shaking. Figure 4 shows that the arching action disappears and the blocks start to fall apart, while the columns slides relative to the base and they tend to topple.

Conclusions: Discrete finite element method (DFEM) was applied to study the response and stability of masonry structures under seismic loading conditions. It is found that the DFEM is a promising method

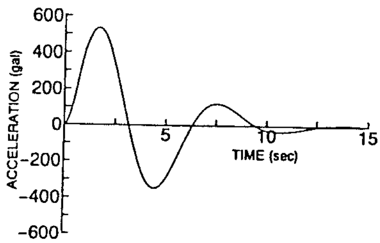

Fig. 1 Imposed lateral acceleration wave on foundation

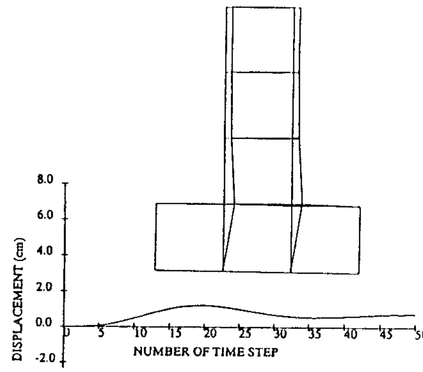

Fig. 2 Initial and deformed configurations and displacement response of the top of a masonry tower

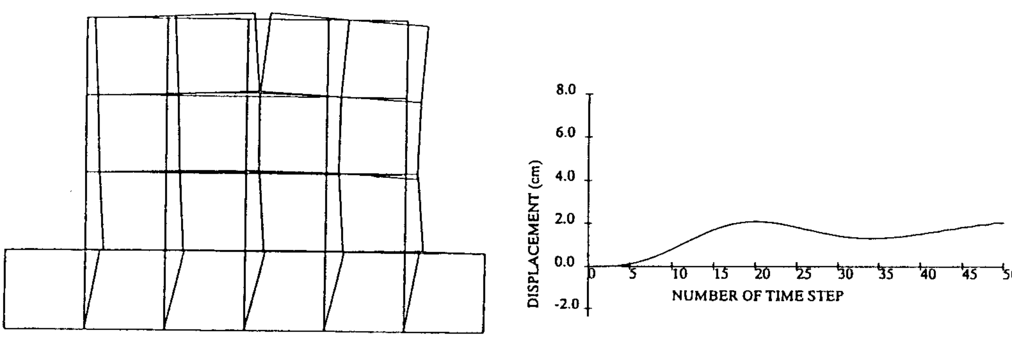

Fig. 3 Initial and deformed configurations and displacement response of the top of a masonry wall

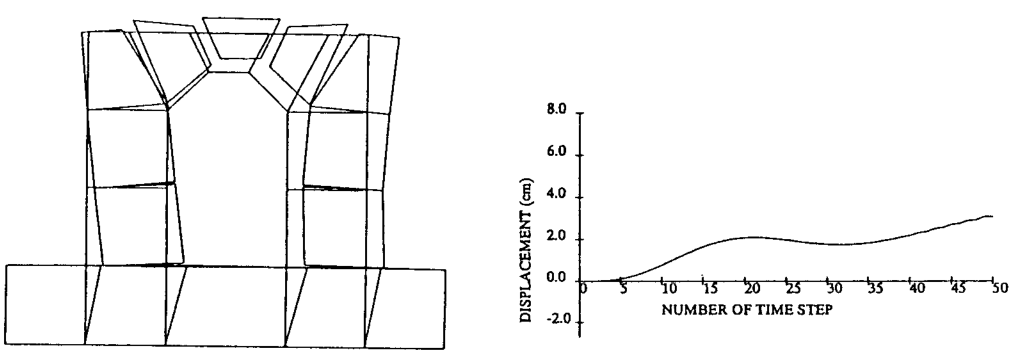

Fig. 4 Initial and deformed configurations and displacement response of the top of a masonry arch

for study the mechanics of masonry structures. Although the examles given are very simple structures, they are to illustrate the fundamental features of the method. One may also consider and analyze more complicated masonry and rock structures by this method. Nevertheless, the proposed hyperbolic scheme is still in its formative phase for which both experiments on viscous characteristics of blocks and contacts as well as numerically stable time-discretisation scheme are felt to be necessary.

References: (1) Mamaghani I.H.P.: "Numerical analysis for stability of a system of rock blocks." *Master thesis*, Dept. of Civil Engineering, Nagoya University, 1993. (2) Mamaghani, I.H.P., Baba, S., Aydan Ö., Shimizu, Y.: "Discrete finite element method for blocky systems." *Proc. of the Eighth Int. Conf. on Computer Methods and Advances in Geomechanics (IACMAG)*, Morgantown, USA, Vol. 1, 843-850, 1994. (3) Mamaghani I.H.P., Aydan Ö, Kajikawa Y.: "Modelling and analysis of masonry structures." *Proceding of the 8th annual meeting, JSCE*, Chubu branch, 115-116, 1997.