

論文

[2147] TWO - DIMENSIONAL DYNAMIC NON - LINEAR FINITE
ELEMENT ANALYSIS OF RC SHEAR WALLSC. M. Song¹ and K. Maekawa²

1. INTRODUCTION

Nowadays the nonlinear dynamic behaviors of RC structures are mainly investigated by experiments, which are very expensive and, in some cases, difficult to perform. Therefore, it is advisable to develop general numerical analysis methods as substitutes for experiments. A numerical method is also helpful in interpreting experimental results. The objective of this study is to develop a general dynamic finite element analysis procedure for RC structures subjected to in-plane dynamic forces. At present, most of the researches on dynamic analysis of RC structures are concerned with frames, columns, beams and other structural elements. Complicated RC structures are usually simplified as frames or columns with lumped masses, because it is easier to find the restoring forces of those structural elements and to solve this kind of structural systems mathematically. The dynamic analysis of frames and other structural elements is based on the equations of motion of the system,

$$[M] \{\ddot{X}\} + [C] \{\dot{X}\} + [K] \{X\} = \{F\} \quad (1)$$

in which $[M]$, $[C]$, $[K]$ are mass matrix, viscous damping matrix and secant stiffness matrix. $\{\ddot{X}\}$, $\{\dot{X}\}$, $\{X\}$, $\{F\}$ are acceleration vector, velocity vector, displacement vector and external force vector, respectively. $[M]$ and $\{F\}$ are easily obtained. $[K]$ can be found from the relations of restoring forces and displacements of structural members which are usually deduced from experiments or numerical static analyses, but several researches have found that the dynamic responses of reinforced concrete structures during severe earthquakes can not be obtained accurately by means of static load-displacement relations [1]. $[C]$, which is one of the most difficult point in such an analysis, is usually solved from damping factors given based mostly on experiences and some experiments.

In this paper, the general finite element method established for static analysis of RC structures [2] is extended to dynamic analysis. This method makes use of two dimensional smeared crack elements for members and discrete crack elements for member junctions. It gave results of RC structures under arbitrary static loading histories in very good agreement to experimental results. From the equilibrium equation of a structure and the path-dependent constitutive model of RC elements, the governing equation can be written as,

$$\{R\} = \{F\} - [M] \{\ddot{X}\} - \iiint_V [B]^T \{\sigma(\varepsilon, t)\} dV = 0 \quad (2)$$

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in which $\{\sigma(\varepsilon, t)\}$ is stress vector which depends on strain and time history, and can be obtained from the constitutive model of RC elements. If a model of RC element can include path-dependent and time-dependent effects, this approach can take into consideration of viscous damping, hysteretic damping and stiffness characteristics at the same time instead of making the cumbersome separation of them as stiffness matrix and viscous matrix. Unfortunately, there is no time-dependent model of RC elements available. The model used in this analysis is only path-dependent. Hence, viscous damping is neglected. $[R]$ is error vector, which should be zero provided a given displacement field is the solution of the problem. Its values is checked in every iteration. Iterating will be performed until the error vector is small enough to satisfy accuracy requirements. The stiffness matrix is used only in predicting displacement increments from error vector. Its accuracy will affect convergence speed of iterating but not the accuracy of final results. This approach is preferred when it is difficult to obtain accurate stiffness or the iteration of Newton-Raphson method may diverge. The accumulated error in solution can be restrained in this method because equilibrium is checked constantly. The numerical procedure used in solving Eq. 2 is explained in Ref.[4]

2. ANALYSIS OF A RC COLUMN WITH A CONCENTRATED MASS

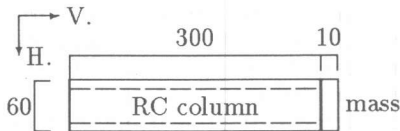


Figure 1: RC Column(cm)

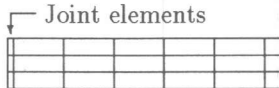


Figure 2: Element Mesh

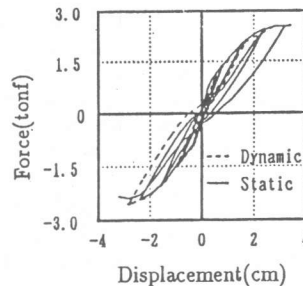


Figure 3: Force vs. Displacement

In order to verify the computer program and demonstrate the different dynamic response characteristics of different kinds of structures, a RC column with a concentrated mass (Fig.1) on its top was computed. Concrete strength is 30MPa. The density of concrete is assumed as zero for simplicity. The reinforcement ratio is 1.5%. The elastic modulus of concentrated mass is assumed to be 100 times of the initial elastic modulus of concrete. The density of the concentrated mass is $2 \times 10^{-4} \text{ kg/cm}^3$. This structure is divided into 3×6 8-node elements and 3 joint elements between the beam and foundation to idealize the pull-out of reinforcing bars from foundation. Total node number is 80(Fig.2). The ratio of width to length of this column is about 1/5 and the mass of the column is neglected. When a single degree of freedom system is subjected to horizontal ground motion \ddot{X}_g , its equation of motion Eq.(2) will be,

$$KX = -M(\ddot{X} + \ddot{X}_g) \quad (3)$$

where X and \ddot{X} are displacement and acceleration of the concentrated mass relative to foundation. $\ddot{X}_a = \ddot{X} + \ddot{X}_g$ is its absolute acceleration. K represents its restoring characteristics. From Eq.3 we can see that if the time-dependent effects of restoration force are neglected the static restoration force-displacement relation should be the same with dynamic one for a single degree of freedom systems. This column was analyzed under a static loading acting on its top and under a ground motion $\ddot{X}_g = 20 \sin\left(2\pi \frac{t}{0.72}\right) \text{ gal}$ by using the [WCOMD]. The relations between loads and displacements of concentrated mass are shown in Fig.3 with the solid and dash lines standing for static and dynamic analysis respectively. We can observe that it is close to the static one with only very small