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DEVELOPMENT OF A NEW EFFICIENT TECHNIQUE FOR NONLINEAR STRUCTURAL ANALYSIS

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1. Introduction

A new method for nonlinear analysis of reinforced concrete structures is proposed. The concrete is modeled as an assembly of distinct elements made by dividing the concrete virtually. These elements are connected by distributed springs in both normal and tangential directions. The reinforcement bars are modeled as continuos springs connecting elements together. Local failure of concrete is modeled by failure of springs connecting elements when the stress calculated from force acting on springs exceeds the critical stress. We developed the element formulation and the computer code and verified the accuracy of the method by comparing the simulated results with theoretical results and experimental results. From the comparison we can say that the proposed model can be applied to determine the failure load, the load-deflection relations, the prediction of crack initiation, crack location and crack propagation.

2. Element formulation

We assume that the two elements shown in Figure (1) are connected by normal and shear springs at one contact point. In the 2-dimensional model, three degrees of freedom are considered for each element and deformations are assumed to be small. The stiffness matrix size is only (6X6). The stiffness matrix depends mainly on the angles θ and α and the distance L. Each element is connected with the surrounding elements by distributed springs set between the element edges. The total stiffness matrix is determined by summing the stiffness matrices of individual spring around each element. Consequently, the developed stiffness matrix is an average stiffness matrix for the element according to the stress situation around the element. Failure of springs is modeled by assuming zero stiffness for the spring considered. In this analysis, each spring is considered to represent deformations and failure of certain part of the element. Consequently, spring stiffness is determined by assuming that each pair of normal and shear springs are representing a certain area of the connected elements as shown in Figure (2). The same formulation also can be used for reinforcement springs to represent reinforcement bars.

3. Simulation of the effects of element size and the number of springs

To investigate the effects of element size, a series of simulations in elastic conditions were carried out using different models of laterally loaded cantilever shown in Figure (3). The results were compared with those obtained from elastic theory. The percentages of error in maximum displacement and the CPU time (CPU: DEC ALPHA 300 MHz) are also shown in Figure (3). To discuss the effects of the number of connecting springs, additional simulations with different number of springs were performed. From the figure, it is evident that increasing the number of base elements leads to decreasing the error but increasing the CPU time. The error reduces to less than 1% when the number of elements at the base increase to 5 or more. In addition, although the CPU time in case of 10 springs is almost half of that of 20 springs, the results of 10 springs congruent with those of 20 springs.

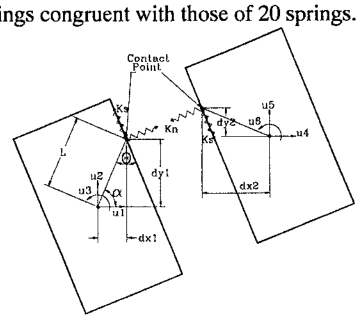

Fig. (1) Element shape, contact point and degrees of freedom for two elements

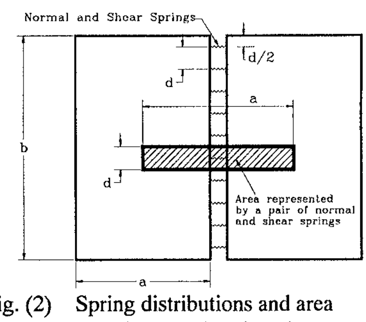

Fig. (2) Spring distributions and area of influence of each spring

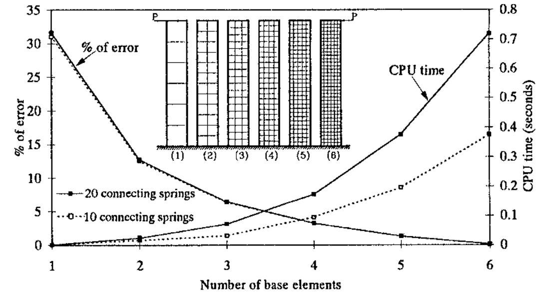

Fig. (3) Percentages of error and CPU time against the number of base elements

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4. Simulation of two-storied RC wall structure subjected to monotonic loading

To verify the accuracy of the model, the simulation results are compared with the experimental results of a two-storied RC wall. The wall shape, reinforcement and loading conditions are shown in Figure (4). For more details about the columns, beams, wall reinforcement or the material properties, see the reference (1). The stress-strain relation for concrete springs subjected to tension was assumed linear till reaching failure of springs. For compression springs, Maekawas's compression model was adopted[2], while steel stress-strain relation was assumed bilinear. The wall is modeled using 1,845 square elements. Figure (4) shows a comparison between measured and calculated load-rotation relations. First, to discuss the effects of load increment in failure analysis, three models of different load increments, calculated by dividing the estimated failure load by 50, 250 and 500, with the constant number (10) of springs were used. Next, to study the effects of the number of connecting springs between faces, additional simulations were performed using the model of 250 load increments with 5 and 2 springs. The failure load calculated in all cases ranged from 64 to 70 tf, the measured one was 67 tf, while using the FEM, it was 64 tf[2]. The results of 50, 250 and 500 increments are almost congruent till at least 90% of failure load. Surprisingly, in case of 250 increments with only 2 springs connecting each two adjacent faces, the result is also reliable till reaching failure of the structure. This means that our model gives reliable results even when few number of connecting springs or large value of load increments are used.

Figure (5) shows the deformed shape during the application of load in case of 500 load increments with 10 springs. The location and propagation of cracks can be easily observed which are very similar to those obtained from the experiment. This indicates that the proposed model can be applied to highly non-linear fracture behavior of RC structures such as, failure load, deformations, crack generation and crack propagation, etc.

5. Simulation of RC deep beam without shear reinforcement bars

Simulation result using a deep beam[3] which does not have shear reinforcement in the shear zone is introduced. The result obtained through our model is compared with the results from experiment and FE analysis as shown in Figure (6). The shape, loading conditions, reinforcement and deformed shape are also shown in this figure. In general, the results of the proposed model is more accurate than that obtained by the FEM. The reason is simply because no reinforcement is used in the shear zone and hence, the sensitivity of the concrete to cracking increases. This effect can not be accurately followed using the FEM.

6. Conclusions

A new numerical technique for highly non-linear fracture analysis of structures is developed. Through comparison of simulation results with theoretical and experimental results, this model was proved to be an efficient technique for fracture behavior of structures.

References

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2) Okamura H. and Maekawa K.: Nonlinear analysis and constitutive models of reinforced concrete, Gihodo Co. Ltd., Tokyo, 1991.
3) Railroad Research Institute and Research Institute of Tekken Co. Ltd.: Study on shear capacity of RC members based on fracture mechanics, Internal report, 1997.

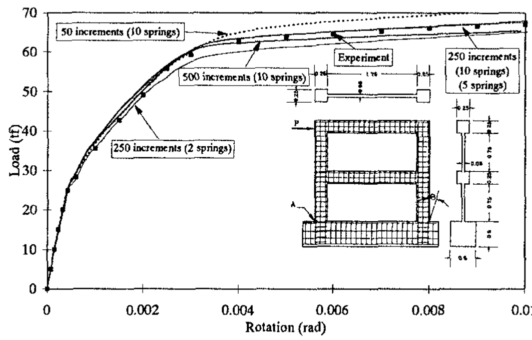

Fig. (4) Relation between load and base rotation for 2-storied RC wall

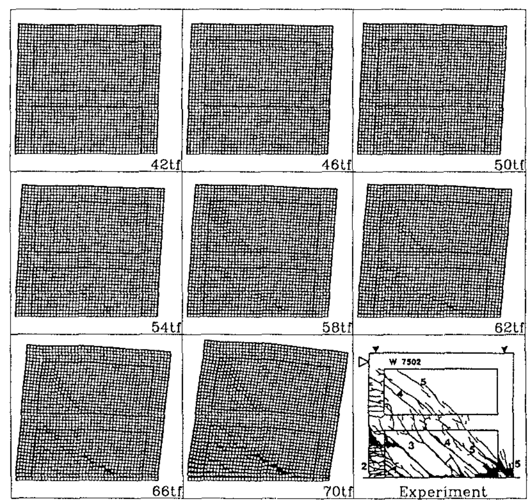

Fig. (5) Deformed shape and crack locations of 2-storied RC wall structure (Scale Factor=30)

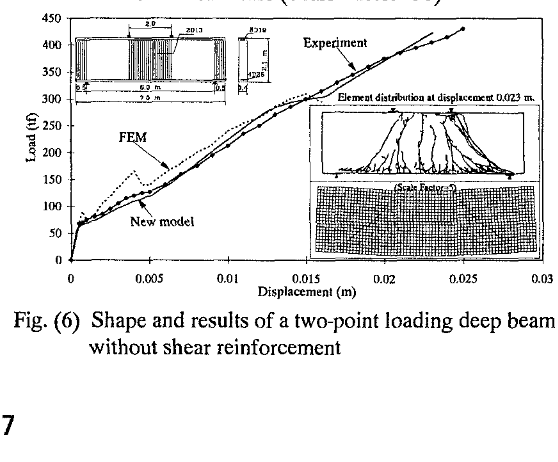

Fig. (6) Shape and results of a two-point loading deep beam without shear reinforcement