Nonlinear seismic analysis of the reinforced concrete and prestressed structures

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1 INTRODUCTION

The seismic response of reinforced and prestressed concrete structures, in addition to other influences, essentially depends on the non-linear properties of concrete and reinforcement. By its nature the non-linearity of concrete and of the reinforcement is very complex and thus it is difficult to model it mathematically in a satisfactory way. The non-linearity of concrete in static conditions is characterized by the elastoplastic behaviour when exposed to compressive stresses and by crushing when the limit of compressive deformation is exceeded. Another properties is the appearance of cracks at tensile stresses resulting in the loss of tesile strength. Non-linearity of the reinforcement is characterised by the elastoplastic behaviour at compressive and tensile stresses, and by strengthening after the increase of the tensile deformations and finally by failure. In order to make a structure, exposed to dynamic loading, safe and efficient it is extremely important to model these phenomena in an appropriate way. The efficiancy of a computational model can be estimated just according to the extent this non-linear behaviour is described.

The non-linear behaviour of reinforced concrete structures exposed to static loads has been modelled by several authors /1,2/. A more complex physical problem, the thermal transient conditions, has been modelled in papers /3,4/. Non-linearity in dynamics and particularly in seismic problems has been modelled in /5,6,7/, and it has not been sufficiently studied.

The numerical procedure presented in this paper deals with all the essential properties of material non-linearity of reinforced and prestressed concrete structures in a simple way. This model is used to study the displacements, velocities, accelerations, deformations, stresses, potential and kinetic energy for each element and for the entire system, at every time step.

2 DYNAMIC MODEL

The chosen dynamic model is a plane model. Concrete and the soil near by foundations are modelled by 2D curvilinear finite elements. Bars and wires of the simple and high-quality reinforcement have been modelled by 1D curvilinear elements, located among the nodes of 2D elements. The material non-linearity of the concrete and reinforcement has been described by means of the stresses and deformations status in the Gauss integration points. The system mass is given distributed over 2D elements and concrectated in the system nodes. The matrix of the system mass can be consist or diagonal. In addition to the damping resulting from the behaviour of the material, the damping can be given as a linear combination of the stiffness matrix and the mass matrix /8/. 2D and 1D finite elements are incorporated into the general nonlinear finite element model /8/. The motion equation has been solved by mixing explicit-implicit time integration step by step scheme /8/. Within each step the iterative procedure is carried out using the method of the constant stiffness matrix /6,10/. The basic motion is given using the accelerogram.

The kinetic energy is computed as one half of the mass and square of velocity product, and the potential energy as the area of the histeresis curve using the discrete values of stresses and deformation in each iterative step. The model can indirectly, by giving the input quantities of the deformations behaviour of the material, accept the size effect.

3 MATERIAL MODELLING

Both a perfect and strain-hardening elastoplasticity approach are employed to model the multiaxial compressive behaviour of concrete. A dual criterion for yield crushing in terms of stresses and streains is employed, which is completed with a maximum tensile stress criterion /1,9/. A smeared representation for cracked concrete, more convinient for finite element formulation, is assumed, which implies that cracks are not discrete but distributed within a sampling volume. The steel behaviour is idealised by an uniaxial elastoplastic model /8/ resisting only the axial force in the reinforcing bar or wire direction.

4 THE DESCRIPTION OF NUMERICAL EXAMPLES

Modelled structure is r/c wall, it is high 8,0, wide 4,0, and thick 0,2 m. It is reinforced by concentrated bars on the edges, and with welded wire fabric along the wall. The geometrical characteristics, disposition of reinforcement and assumed finite element mesh are shown in Fig. 1. The material properties for both concrete and steel are given in Table 1. The mass of nonconstructive structural parts is added to the wall mass.

Two examples are observed, each out of the gravitation field. The damping is neglected for linear structure response. Only the material damping is accepted for non-linear structural response. The ground motion is assumed according to accelerogram of the earthquake Petrovac, Yugoslavia 1979 at Fig. 2, which belong to strong earthquake.

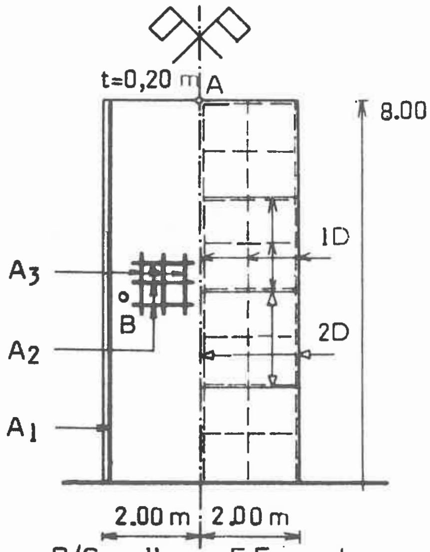

Fig. 1. Reinforced concrete wall

Table 1: Material properties

Concrete	
Young's modulus	30 000 MPa
Poisson's ratio, ν	0.17
Compressive strength, Fc'	30.0 MPa
Tensile strength, ft	3.0 MPa
Compressive strain limit	0.035
Steel	
Young's modulus, Es	220 000.0 MPa
Yields stress, σ_y	420/560 MPa
Strain limit	0.10
Area of reincorcement	A_1=0.0009 m² A_2=A_3=0.0004 m²/m
Mass density, ρ	20,0 t/m³

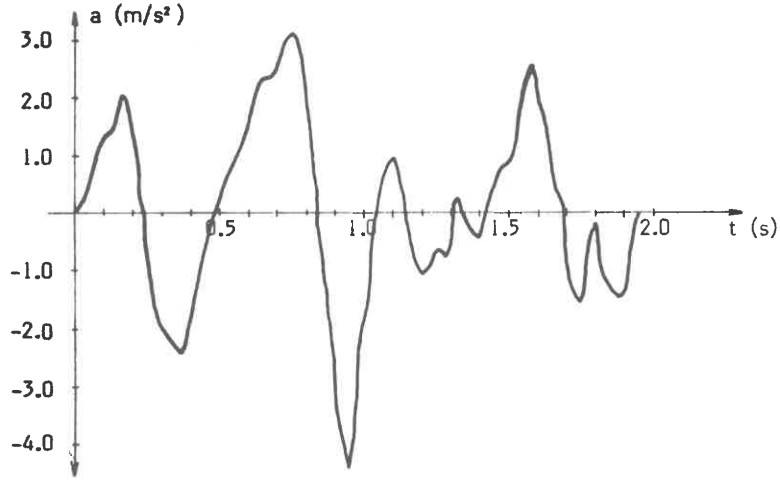

Fig. 2. Accelerogram of the earthquake Petrovac, Yugoslavia, Hotel Oliva, April 15 1979, from t=10,24 s up to t=12,24 s. (N-S)

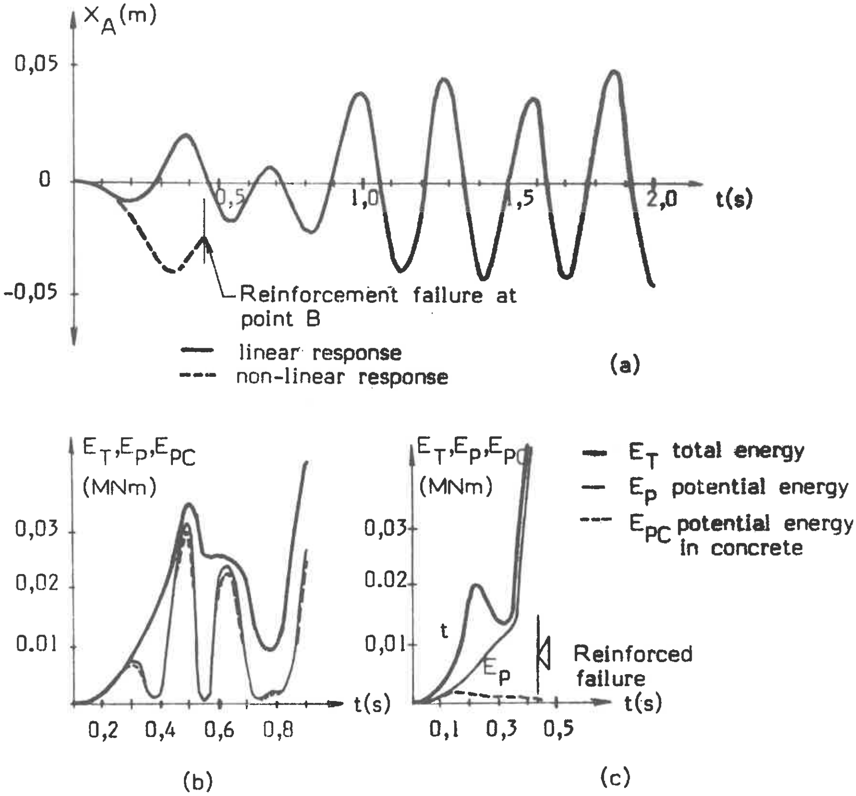

Figure 3. The response of r/c wall, a) horizontal displacement of the top of structure for linear and non-linear behaviour, b) diagram of the energy for linear behaviour, c) diagram of the energy for non-linear behaviour

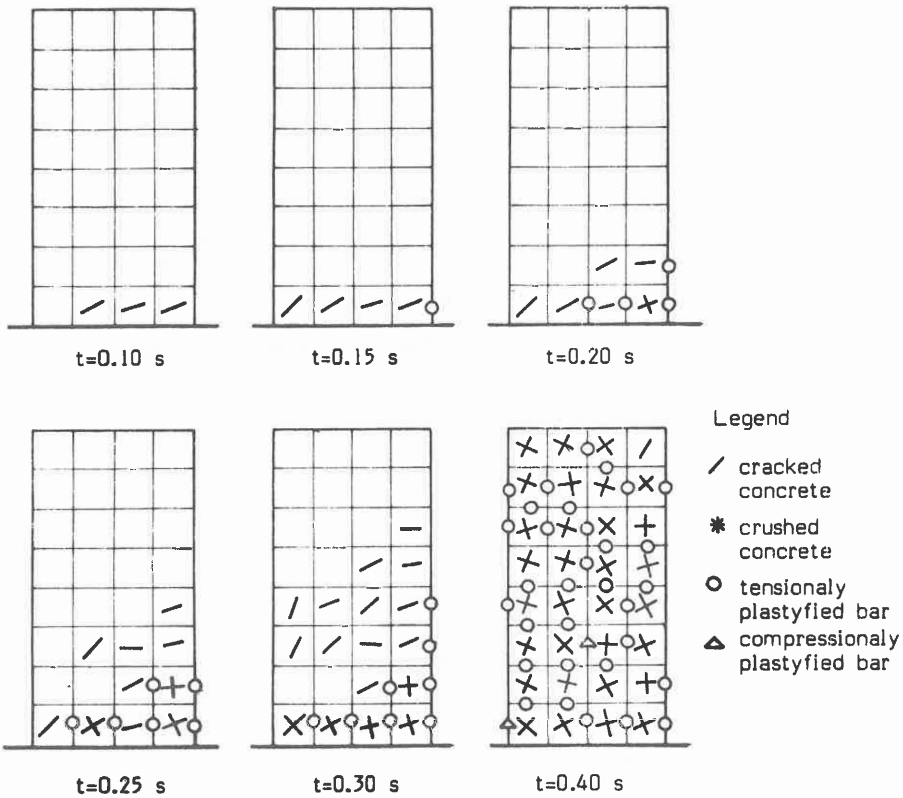

Figure 4. Cracked and plastyfied zones at different time steps.

5 SUMMARY AND CONCLUSION

The presented numerical model can be applied in research and practical engineering projects. The model has been tested by the computer programme MIXDYIN /8/ for the linear response and it desplays a very good agreement of the results. The accuracy of the iterative procedure for the non-linear response is conditioned by the norm of the residual forces as in /8/.

The energy computation in the system is very sensitive to the time increment due to the very complex form of the histresis of concrete. Approximately, the time increment step should be selected in the same way as with the explicit method.

The results of the considered example Figs. 3 and 4, as well as the results given in /10/ show that the responce of r/c is prevalently dependent on the cracks in concrete and on the plasticity properties of the reinforcement.

The comparison of the linear and non-linear responses shows the loss of energy in the system occuring until the moment of the system failure. The energy rapidly increases immediately before the failure of the system. The failure of the structure results from the tensile yield of the reinforcement. It can be noted that, at linear response, concrete contains over 95% of the potential energy of the system, whereas at non-linear response concrete contains below 5% of the potential energy. This small quantity of potential energy in concrete shows that the r/c wall under consideration has no ductility. According to the chosen dimensions the wall belongs to the group of shear walls. In addition to the tensile plastification of the reinforcement, which is dominant, the compressive plastification has been noted as well.

The considered examples do not take into account either soil effect or the size effect.

6 REFERENCES

/1/ F.Damjanić "Reinforced Concrete Failure Prediction under Both Static and Transient Conditions". Ph.D.Thesis, C/Ph/71/83, University of Wales 1983.

/2/ H. Kupfer, H.K. Hilsdorf, H. Rusch "Behaviour of Concrete under Biaxial Stresses". ACI Journal, Vol. 66, No. 8, pp 656-666, Aug. 1969.

/3/ N.Bičanić "Nonlinear F.E. Transient Response of Concrete Structures". Ph.D. Thesis C/Ph/50/78 University of Wales 1978.

/4/ F. Damjanić "A Finite Element Technique for Analysis of Reinforced and Presstresed Concrete Structures", Europe-U.S. Symposium on Finite Element Methods for Nonlinear Problems, paper I.15, Trondheim, August 85.

/5/ A.B. Agraval, L.G. Jäger, A.A. Mufti "Response of RC Shear Wall under Ground Motions". Journal of the Structural Division, Feb. 81 pp 395-411.

/6/ A. Mihanović, B. Jaramaz and F. Damjanić "Finite Element Analysis of Seismic Response of Reinforced Concrete Walls". Proc. of the Int'l Conf. on Computational Mechanics, p IV-273-277, May 86, Tokyo. Japan.

/7/ A. Mihanović, B. Jaramaz, F. Damjanić, "Finite Element Analysis of Seismic Response of Reinforced Concrete Structures". Proc. 8th European Conference on Earthquake Engineering, p 6.4.33-6.4.38 Lisbon, Sept. 86.

/8/ D.R.J. Owen, E. Hinton "Finite Element in plasticity". Pineridge Press Limited, Swansea U.K. 80.

/9/ E. Hinton, D.R.J. Owen "Finite Element Software for Plates and Shells" Pineridge Press Limited, Swansea, U.K. 84.

/10/ A. Mihanović, F. Damjanić "Analysis of Nonlinear Dynamics Response of Reinforced Concrete Structures". Proc. of the Int'l Conf. Numerical Methods for Nonlinear Problems, p 1238-1246, Dubrovnik 1986.

/11/ D. Petrovski, N. Naumovski, S. Stamatovska "Bulletin of the Strong-Motion Earthquake Accelerogram". No. 1 1984. IZIIS University of Skopje, Yugoslavia.