Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Numerical-experimental study of the reinforced concrete shear-wall behaviour under the seismic excitation

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ABSTRACT: The paper presents some results of the numerical-experimental analysis of the RC shear-wall model behaviour. Numerical analysis of the Single-Degree-of-Freedom (SDOF) system behaviour under the earthquake-type excitation has been coupled with the stiffness and displacement data of the real shear-wall model behaviour. The stiffness has been measured throughout the model experimental testing, simultaneously with the numerical analysis. Between the successive time steps, force-displacement data have been approximated by a polynomial function, and the stiffness has been obtained as a first derivative of the polynomial at the end point. This value served as an input data for the numerical analysis in each time step. Relative displacements obtained from the numerical analysis have been given as an input to the testing system, and the top of the shear-wall model has been displaced to the desired value. In the attempt to measure and calculate the current stiffness values of the physical model in the numerical-experimental procedure performed with the standard measuring devices and acquisition systems, certain difficulties are always present. Proposed procedure cannot completely eliminate the measurement problems. Authors of the paper believe that the problem might be solved in one of the following ways: *a)* by using more precise measuring devices or *b)* by using another numerical procedure.

1 INTRODUCTION

In spite of the numerous existing models and continuous research efforts, it is very difficult to define the RC hysteretic behaviour by means of a single and unique analytical model which could be able to simulate realistically the reinforced concrete (RC) element response to all practically possible load histories.

At present, there exist a large number of hysteretic models incorporating various rules for the RC behaviour under the cyclic loading actions. Complexity level of these models varies from simple to extremely complicated ones, trying to predict the RC element behaviour in the most realistic way.

Normally, a dynamic analysis program module which defines the hysteretic element behaviour is the most complex program part, which causes certain errors in the analysis. However, this is not a matter of numerical errors, because these errors could be eliminated to the satisfactory degree. The reason lies in the unavoidable simplification of the real element behaviour.

This paper presents some results of the numerical-experimental analysis of the RC shear wall model behaviour. The numerical analysis of the SDOF system behaviour under the earthquake-type excitation has been coupled with the data on the real shear-wall model behaviour. Experimental model has been excited by the same acceleration record as the numerical one.

2 METHOD

2.1 Basics of the proposed procedure

Authors of the paper consider the proposed procedure as a basically numerical one. The numerical analysis is carried out in discrete time intervals, and in each moment the real model stiffness has been taken as an input data for the numerical analysis. The stiffness has been measured throughout the model experimental testing, simultaneously with the numerical analysis. In this way, there is no need for a program module which would be bound to predict the model hysteretic behaviour. This module has been substituted by another one, which has a task to acquire the measured data, and also to control the experimental process.

Equation of motion which defines top of the model displacement is as follows:

$$m\Delta\ddot{x} + h\Delta\dot{x} + k(t)\Delta x = -m\Delta\ddot{u} \quad (1)$$

where : m - mass of the system, h - viscous damping ratio, Δx, $\Delta\dot{x}$, $\Delta\ddot{x}$ - relative displacement increment and its time derivatives (velocity and acceleration), k(t) - current stiffness of the system.

Ground acceleration $\ddot{u}(t)$ is a given value, being acceleration record of an occurred or a synthesized earthquake.

Numerical integration of the equation (1) is usually performed by one of the direct dynamic analysis procedures, depending on the problem nature. In this case, one of the Newmark family of algorithms (linear acceleration method) has been utilized.

As is well known, if at the discrete instant of time t values $x(t)$, $\dot{x}(t)$, $\ddot{x}(t)$ and $k(t)$ are known, then it is possible to obtain, for some time increment dt, new values of displacement, velocity, acceleration and stiffness ($x(t+\Delta t)$, $\dot{x}(t+\Delta t)$, $\ddot{x}(t+\Delta t)$, $k(t+Dt)$). Attained value of the displacement $x(t+\Delta t)$ can be given to the testing system (hydraulic system and electronic control devices), and consequently the model can be displaced to the desired value. At that moment, load-cell force increment ΔP, should be measured, and the new stiffness value $k(t+\Delta t)$ will be obtained. The current stiffness value is equal to the force increment/displacement increment ratio (dP/dx).

2.2 Determination of the current model stiffness

From the previously described procedure, it could be concluded that determination of the current stiffness is a simple thing. Problem is, however, quite complex. Numerical procedure requires a small time increment Δt. Small time increment leads to the small increments of force ΔP and displacements Δx which are difficult to determine with sufficient accuracy. Difficulty is not so much related to the accuracy of the measuring systems, but more with their resolution. If the rather large model displacement is required in order to take into account the inelastic behaviour, then measurement resolution has been reduced inevitably, and that leads to the difficulties in determination of the model stiffness and less reliable results. Thus, the following approach has been adopted: From the point $x(t)$ to $x(t+\Delta t)$ a series of successive force (P) and displacement (x) values have been measured, each of them several times. The series of values have been approximated by some suitable function. First derivative of the function (dP/dx) at the end point represents the current model stiffness. It has been thought that for this purpose a third degree polynomial is a most suitable function. For definition of the polynomial, besides the measurements in the current step, all the measurements from previous step have been recorded. Polynomial has been determined on the basis of all mentioned measurements by the least square method.

In all the alternatives none of the points, except for the first one, should be "Return point", i.e. the point in which velocity changes sign. The "Return point" has been treated as a "Starting point". At this point, another procedure for stiffness determination is valid. Several small, bu sufficiently large displacements as compared to th resolution, have been given to the model, and a relevant measurements have been carried ou From the linear regression analysis new stiffne for determination of the next-step displacemer $x(t+\Delta t)$ could be defined. Process continues in th previously described manner.

3 PRESENTATION OF THE EXPERIMENT

3.1 Model Description

Large-scale model represents a prefabricated shear-wall with the welded steel connections anchored in the RC anchorage block (Petrović 1990). Model has been equipped with the number of strain gauges and inductive displacement transducers. All the relevant measurements have been directly recorded by electronic acquisition systems. Process has been controlled through a PC-AT computer. Complete software for the process control and data acquisition has been developed by the second author.

3.2 Experimental Procedure

Experiment has been carried out in several phases. Each of them has been treated as a separate "run", i.e. separate numerical analysis. As an excitation function, parts of the Montenegro,1979 accelerogram record (Ulcinj,15.4.1979.,N-S component) have been used, and the acceleration level has been scaled to the desired response level.

As the model has been rather stiff, much stiffer than the full-size structure, in order to get response to the excitation, a fictitious mass has been used in the numerical analysis instead of the real one. In this way, analytical system with the period of approximately 0.7 sec. has been obtained (for the initial stiffness level). Viscous damping ratio (2% of the critical value) has been introduced in the analysis.

3.3 Results

In the Figure 1, the stiffness time history (K-t) obtained by the described procedure is presented. This relation has been compared with the stiffness data measured directly from the "Force-Displacement" (P-x) hysteresis curves in the ultimate phase of the experiment, Figure 3. Tangent stiffness obtained from the P-x curve represent the approximate values, but the curve is rather smooth as compared with the real stiffness time history. The results obtained in both ways come along pretty good.

Determination of the jump in the stiffness value at the "Return point" represents a particular difficulty, and these results, at least in our case, could not be sufficiently reliable. This can be clearly observed on the "Displacement Time History" curve (x-t), Figure 2. To the right of the second peak (minimum) value, certain irregularities are visible.

In order to more realistically describe the cyclic behaviour of RC elements with dominant flexure behaviour, a hysteretic Degrading Strength and Stiffness (DSSM) model has been formulated earlier by the authors. Model has some characteristics of the previously developed models (i.e. Clough's, Takeda's), but at the same time

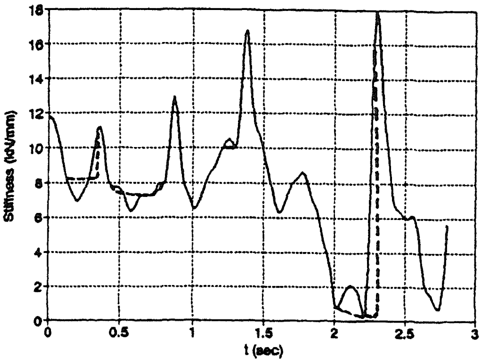

Figure 1. Stiffness Time History

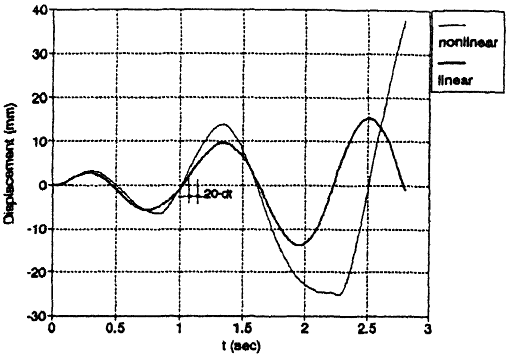

Figure 2. Displacement time history

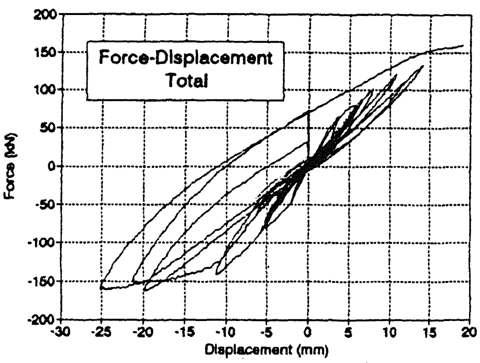

Figure 3. Total "Force-Displacement" History

represents a certain extension, having the possibility to describe the strength degradation upon reaching the ultimate strength value. Stiffness degradation is a function of the maximum attained displacement and the plastic excursion value. Characteristic features of the model have been presented elsewhere (Nikolić-Brzev 1989). Figure 4 presents the Force-Displacement response and Displacement Time History obtained as a result of both the analysis and experiment. Experimental data are taken for the ultimate phase of the experiment.

4 CONCLUSIONS

In the attempt to measure and calculate the current stiffness values of the physical model in the numerical-experimental procedure performed with the standard measuring devices and acquisition systems, certain difficulties are always present. Newmark's procedure, applied in the test, although widely used in numerical analyses, is not the most convenient one for the "On-line tests". It involves measurements of the force and displacement increments, what requires instruments with very high resolution. Without such equipment, the stiffness value, as the basic input data for calculation, would be insufficiently accurate one. The "Finite differences" numerical procedure requires force and displacement measurements instead of measuring their increments, and it would be more convenient and more accurate one. However, the Newmark's "on-line" procedure could be improved. It is obvious that the time step (Δt) used in the numerical analysis should not remain the same in the "Determination-of-the-current-stiffness" procedure. On Figure 2 it can be observed that one relatively linear part of the curve comes through approx. 20 time steps Δt. Therefore, it may be taken that the stiffness has a constant value in that interval. This fact yields the option to use larger displacement increment Δx while measuring the current load-cell force value. In that way, larger force increments ΔP could be obtained as well. Besides this, the procedure would remain the same, as it has performed in the acceptable way. In the numerical part of the procedure, the stiffness would be kept constant in the range of 10 to 20 time steps (Δt), and then it would be changed gradually. Obviously, the "Return point" must not lie in the interval of current stiffness, except in the case it is the "Starting point".

ACKNOWLEDGMENTS

The research reported in this paper has been supported by the Scientific Fund of Serbia (Grant No.1703), the IMS Institute and by the National Science Foundation under NSF Grant No JFP 696. Their financial support is gratefully acknowledged.

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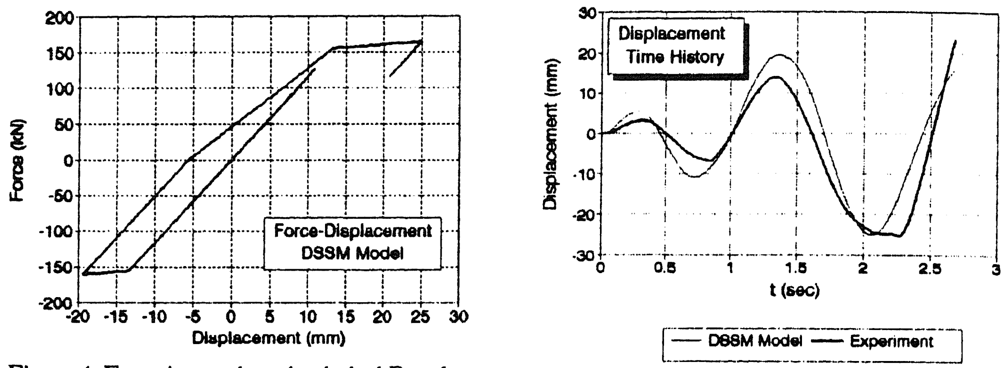

Figure 4. Experimental vs. Analytical Results

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