STRUCTURAL ASSEMBLAGE OF SHEAR WALL HIGH-RISE BUILDINGS EXPOSED TO CYCLIC LOADING

Drazen ANICIC[I] and Mihaela ZAMOLO[II]

SYNOPSIS

The results of laboratory testing of a structural assemblage of shear wall high-rise building are presented. Four large RC models (scale 1:2) were tested. They represent characteristic connections between the shear wall and lintel beams in a residential building of 20x20 m plan dimensions and 19 story height. Characteristic hysteresis loops, dependence of the damping coefficient on the introduced rotation and strain distribution in the main reinforcement are given. The elements were loaded mainly by bending, and shear stresses were moderate (approximately $0.8\sqrt{f'_c}$ kg/cm^2).
The cyclic loading was slowly alternating by successive increase in the rotation amplitude. The analytical model representing the behavior of the assemblage was determined in the manner which was suitable for computer postelastic analysis.

INTRODUCTION

The industrialized mode of construction of residential high-rise buildings in Yugoslavia has been carried out in reinforced concrete. In seismic regions of the western part of the country the "Industrogradnja" system has been successfully introduced. The system benefits from the advantages of a fast construction by means of sliding forms. The bearing system consists of RC shear walls in both orthogonal directions (Fig.1.) weakened by door openings, as well as of full slabs laid on 3 or 4 lines. Floor slabs are concreted in two or three days after the construction of walls, and connections with the walls is achieved by bars which pass through special openings left in the walls. The standard height of these buildings is 16 - 22 stories. The system has been designed in such a way that the disadvantages of open frame structures are avoided (Fintel, 1974).

As it has been known from earlier studies as well as from direct observations of earthquake-damaged similar buildings, the weakest point in such a type buildings are lintel beams. Since they represent an element of minor importance to the transfer of vertical loading, it is useful to investigate the ability of energy absorption of these elements during a strong seismic action.
The works of Paulay (1975) and others indicate that these lintel beams can be, by special oblique crosswise reinforcement, used for the predicted purpose, and that they have a satisfactory ductile behavior. This paper illustrates the second part of the earlier initiated research (Anicic,Zamolo, 1975). The earlier research has shown that it is not possible

---

I Head, II Research Engineer, Structural Research Laboratory, Institute of Civil Engineering of Croatia, P.O.Box 296, Zagreb, Yugoslavia

to maintain by the available distance holder an absolutely fixed distance between the two parts of the walls with simultaneous translation of one portion of the wall in relation to the other portion. The earlier research has shown that the yielding occurs only in two border sections of the lintel beams near the walls.
Therefore, the distance holders were removed from these tests. The M-diagram in the lintel beam corresponds now to the diagram of the cantilever. The models were tested in the position rotated for 90 degrees (Fig.4.).
Since the lintel beams were reinforced by densely laid stirrups and shear stresses were moderate, the postelastic behavior was manifested by yielding in one critical section only, that is on the lintel beam - wall connection.
The models were made in scale 1:2 in relation to the actual structure, and they included one half of the story above and below the floor slab (Fig.2 and 3.).The concrete of the nominal strength of 300 kg/cm^2 (cube) and reinforcement with the yield point of 2500 (main reinforcement) and 5500 (stirrups) kg/cm^2 were used in model manufacture. The age of models at the moment of testing was about six months.

TESTING EQUIPMENT AND INSTRUMENTATION

Quasidynamic loading with slowly alternating forces has been used for the simulation of seismic action of high intensity. Electrohydraulic equipment operating on the principle of the closed loop system has been employed. In the system force - deflection the deflection has been used as a controlled variable and measured by means of the LVDT, and plotted by the XY recorder. Strains have been measured by means of strain gages glued on the bars prior to concreting and recorded for about 25 measuring points for all the loading peaks and all the zero deflections by means of the digital data acquisition system. The closed system of forces has been obtained by means of steel frames attached to the rigid floor. Testing arrangement is shown in Fig. 4.

TEST PROGRAM AND RESULTS

All the four models have been tested in a similar loading history with a successive increase of rotation amplitude up to the failure. The initial rotation has been equivalent to the yield limit, while the final one has been five to six times larger (Fig.5.).The actual failure of the models has not been attained but the occurrence of a complete loss of stiffness, pullout of the reinforcement on the anchorage and large cracks in the concrete have been regarded as a failure. Such a failure occurred after 22-28 loading cycles.
On the basis of the data obtained by the tests one can draw the following conclusions:

1. the damage of the models and the energy absorbtion have been concentrated in one critical section;
2. the stiffness deterioration in repeated cycles of the

rotation amplitude has not been markedly stressed (the number of cycles of equal rotation has been only 4-5);

3. the stiffness deterioration increases by the rotation increase; the envelope of hysteresis loop peaks can be presented in a bilinear form (Fig.10.);
4. the strains in stirrups remain in the elastic region which is caused by the moderate shear stresses ($0.8\sqrt{f_c'}$ kg/cm^2) as well as by densely laid stirrups. The Z coefficient which determines the confining degree of RC in the falling part of the stress-strain curve for concrete (Park and Paulay,1975) amounts to 25-50 which indicates a well-confined concrete;
5. the measured strains in the main reinforcement have been higher than 1 per cent (Fig.7.);
6. the properties of the plastic behavior of the models expressed by the energy ratio and plasticity ratio reveal a linear dependence of these two parameters; it can be expressed by a simple formula

$$\sum_{i=1}^{n} e_i = C_m \sum_{i=1}^{n} \pi_{di}$$

   where C_m = 9-15, n - the number of loading cycles (Fig.8.). The energy ratio has been determined as $e=W/0.5\,P_p \cdot \Delta_p$ where W represents the hysteresis loop area, and the denominator represents the absorbed energy at the yield limit. The plasticity ratio has been determined as $\pi_d = \Delta'/\Delta_p$, Δ' is the remaining deformation at P=0, Δ_p is the deflection at the yield limit;
7. the damping coefficient has been calculated for each cycle according to the formula

$$\xi = C/C_{CR} = W/4\pi W_{el}$$

   that is as the ratio between the absorbed and the elastic potential energy. The dependence of this coefficient on the rotation value has not been determined. The values of the damping coefficient vary between ξ = 0.03 - 0.11,with mean values of 0.056 (models 7 and 8) and 0.069 (models 9 and 10) (Fig.9.);
8. the fitting of the tested hysteresis loops by means of analytical expressions has been carried out in the way similar to that shown by Townsend (1972). In each quadrant the part of the hysteresis loop has been presented by a parabola passing through the loop points of the abscisses o, $\phi/2$ and ϕ. This procedure has been repeated in six different rotations. Parabolas' constants are the second power function of the rotation, and they are calculated by correlation analysis under the condition that the sum of the squares of errors is minimum. Thus, each quart of the loop has been presented analitically by the fourth power polynomial in non-dimensional coordinates: M/M^y on the ordinate and ϕ/ϕ^y on the abscissa. The procedure has been developed for the computer, and results it gives are W area and damping coefficient as a as well as parabolas' constants. An illustration of the relationship between the measured and calculated hysteresis loops is given in Fig.11

The resulting compatibility has been regarded as satisfactory;

9. analytical models are being developed by the use of the stress-strain relationship for concrete and steel for cyclic loading according to the methodology presented by Park and Paulay (1975) by the distribution of the RC section into the narrow strips;
10. analytical models are related to the postelastic behavior of the RC section; analytical models for postelastic behavior of structural elements will be needed in future.

ACKNOWLEDGMENT

This paper is part of a wider research sponsored by the Council for Research of Croatia and the Institute of Civil Engineering of Croatia, Zagreb, Yugoslavia.

REFERENCES

1. Anicic D., Zamolo M.: Stiffness Deterioration of Cyclic Loaded RC Structural Elements, V.ECEE,Istanbul,Sept.1975, P.113;
2. Anicic D., Zamolo M.: Seismic Resistance of Structural Assemblages of RC High-Rise Buildings, Rep.01-7/75,ICEC Zagreb, 1975 (in Croato-Serbian);
3. Anicic D.: Stiffness Deterioration of RC Elements Exposed to Seismic Actions, Ph.D.Thesis,Univ.of Zagreb, 1976;
4. Fintel M.: Ductile Shear Walls in Earthquake Resistant Multistory Buildings, Journal of the ACI, Vol.71, June 1974;
5. Park R., Paulay T., Reinforced Concrete Structures, A Wiley-Interscience Publication, J.Wiley & Sons, New York, 1975;
6. Townsend W.H., The Inelastic Behavior of RC Beam-Column Connections, Univ.of Michigan,Ann Arbor, May 1972.

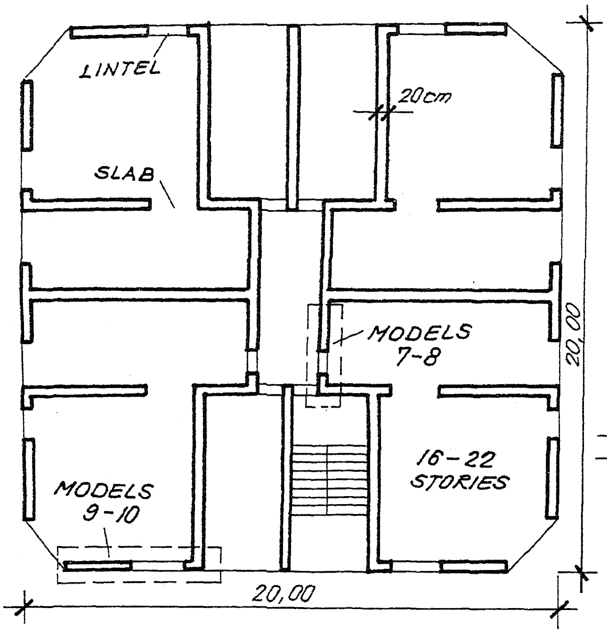

Fig.1 Hor. section

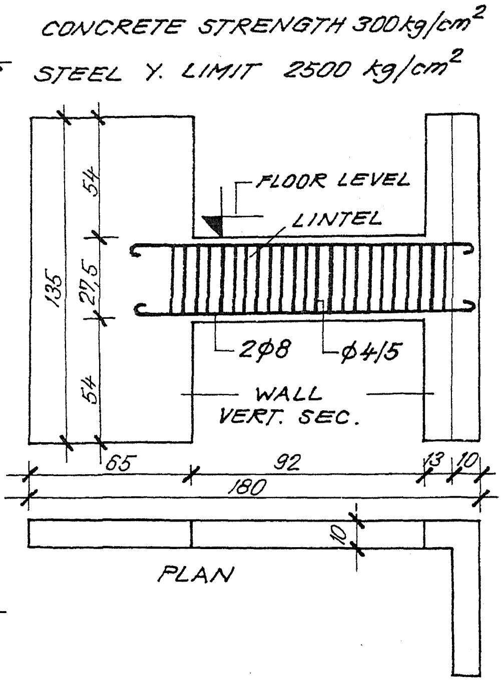

Fig.2. Models 9-10

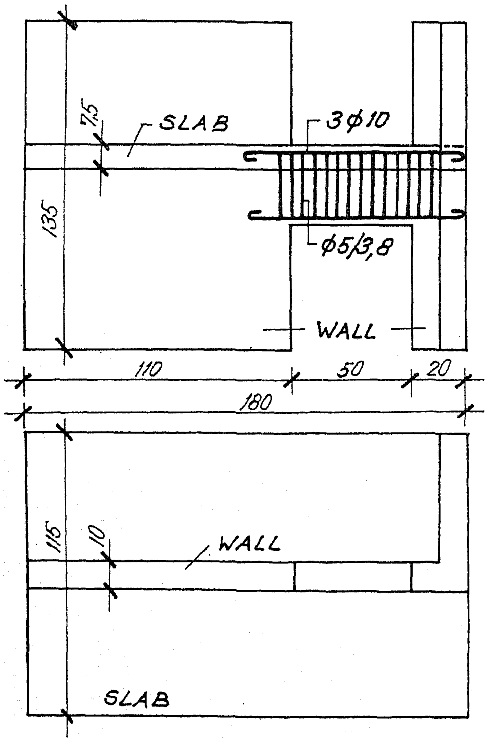

Fig.3 Models 7-8

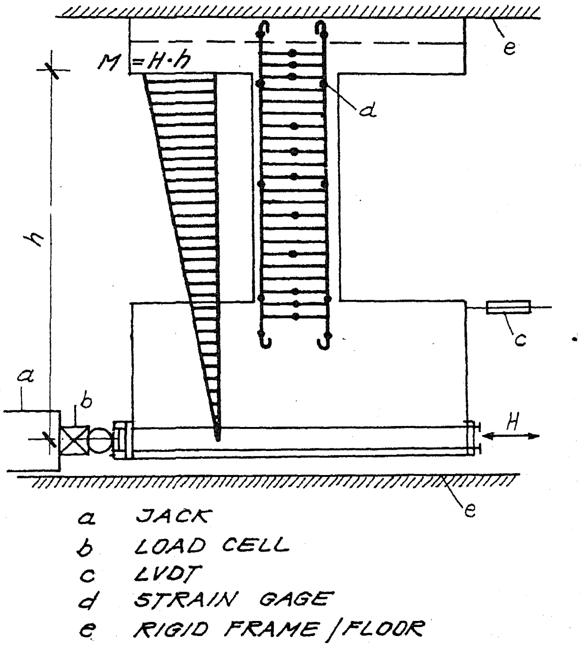

Fig.4 Testing arrangement

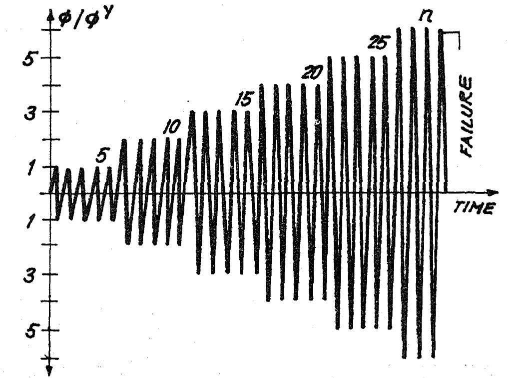

Fig.5 Typical loading history

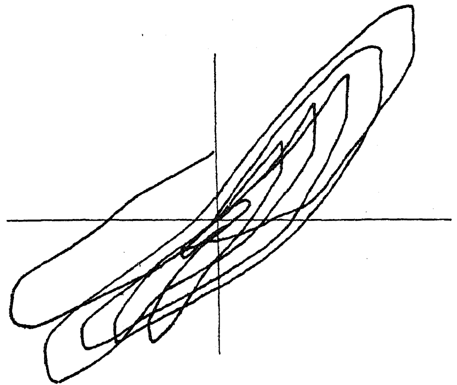

Fig.6 Typical hysteresis loops

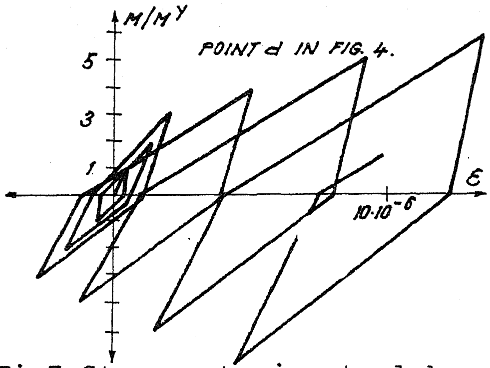

Fig7 Stress-strain:steel bar

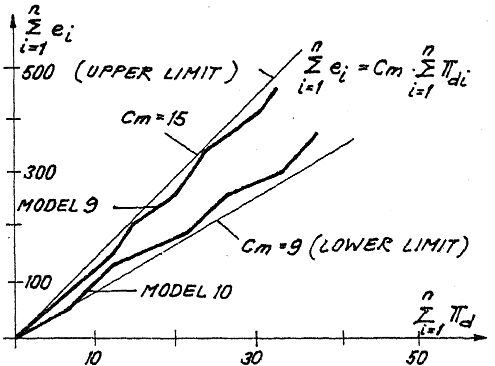

Fig.8 Relation $\Sigma e : \Sigma \Pi_d$

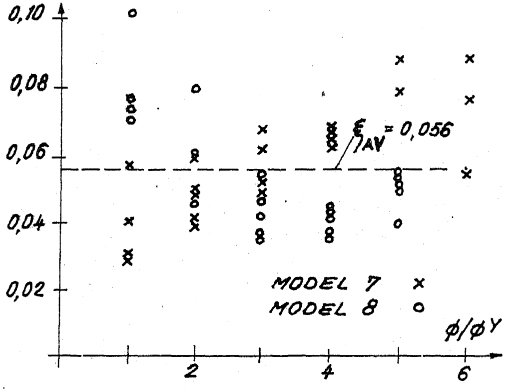

Fig.9 Damping vs. deflection

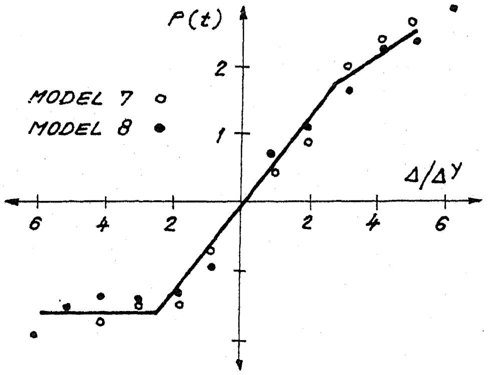

Fig.10 Hyst.loop envelope.

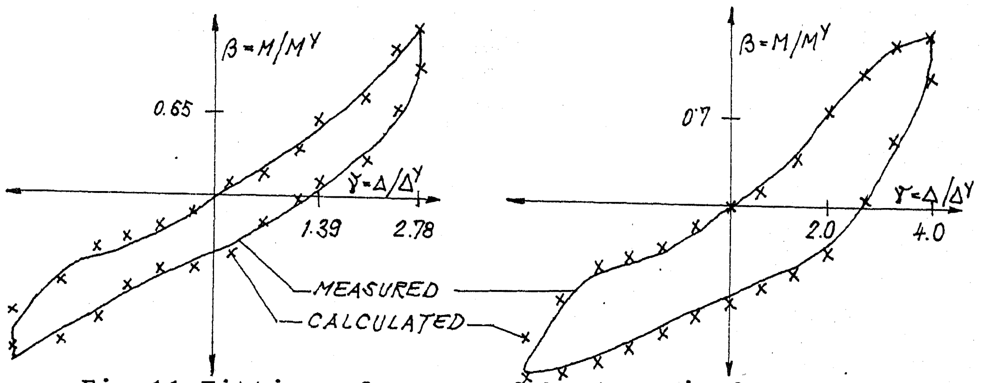

Fig.11 Fitting of measured hysteresis loops