Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VII)

12-3-8

RETROFITTED OPEN GROUND STOREY BUILDING DAMAGED BY EARTHQUAKE - AN EXPERIMENTAL STUDY

I. ROSENTHAL, M. ADIN, D. YANKELEVSKY and M. ITSKOVITZ

Faculty of Civil Engineering, Technion - Israel Institute of Technology
Haifa, ISRAEL

SUMMARY

In r.c. frame-structure buildings with an open ground storey, earthquake damage is mainly local, so that they can be retrofitted instead of being pulled down and re-erected. Two retrofitting techniques were tested on microconcrete models, and their efficiencies were evaluated by comparing the frequency response functions obtained before and after retrofitting. These techniques can also be used as aseismic prevention measures in existing buildings of that type.

INTRODUCTION

R.c. frame-structure buildings designed with an open ground storey to be used as a playground, and sometimes car park (Fig. 1), are known to be vulnerable to seismic action - even to a moderate one - with the ground column-beam joints mainly affected and with the attendant drastic impairment of the lateral resistance of the whole structure (Ref. 1).

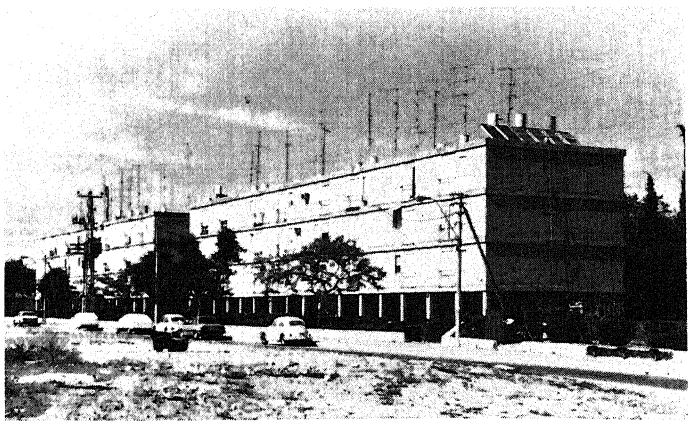

Fig. 1 - Typical three-storey apartment buildings on an open ground storey. Buildings of this type with four storeys served as prototype.

The local character of the damage makes it possible to retrofit the building, instead of re-erecting it. Commonly used retrofitting techniques include supplementary shear walls, strengthening of the columns, epoxy injection (Ref. 2), as well as post-tensioning (Ref. 3), depending on the mode and degree of damage. The efficiency of the retrofitting technique can be evaluated analytically by comparison of the pre- and post-retrofit seismic Index of Structure (Is-index), a parameter based on the strengths and ductilities of the members, their structural profile and time-dependent deterioration (Ref. 4).

OBJECT AND SCOPE

In the present study the efficiency of two retrofitting techniques, suitable for the type of building in question, was established by a comparative procedure as above on microconcrete models, assembled on a shaking table and representing a portion of a five-storey multiple-span apartment building.

The series comprised El Centro (1940) earthquake excitation, at different intensities and times adjusted to the model's scale, as well as free-vibration tests carried out between the dynamic tests, to detect the changes in model characteristics in the various stages up to damage.

PROTOTYPE, MODEL, MATERIALS

A typical multiple-span apartment building consisting of five reinforced concrete frames with three spans in the transverse direction - served as prototype. The floors had ribbed slabs with hollow-block infill spanned in the longitudinal direction. Concrete block walls were used in the facade, as well as in some crosswalls, in all storeys - except the ground storey. Actually, some walls - at least those of the staircase - do exist in the latter but they were not allowed for in the models, which thus represented a more unfavorable situation for the structure.

The size of the models (Fig. 2) was restricted by the limited carrying capacity (50 kN) of the shaking table (3x3m single-degree-of-freedom horizontally operated and controlled by an MTS closed-loop system). Accordingly, only 38% of the prototype length was represented in 1:7.5 scale models, using the Artificial Mass Simulation (AMS) method. The models thus obtained were large enough to permit experimental study of the prototype, including the cracking, damage, retrofitting and failure stages.

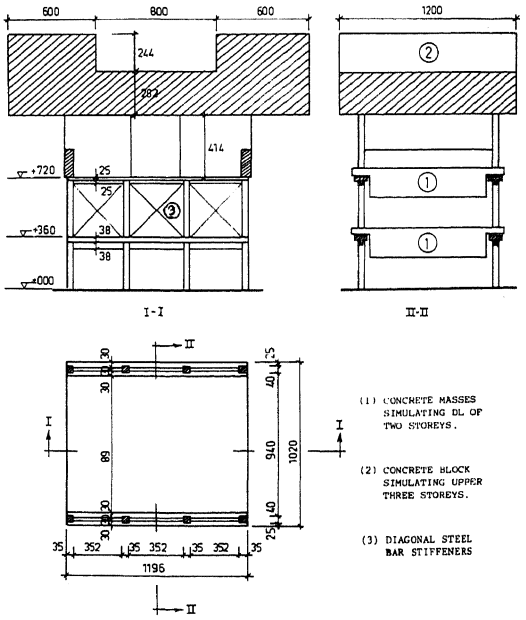

Fig. 2 - Plans of reduced-scale microconcrete model (1:7.5).

Dynamic computer analysis showed that the upper storeys behave as a relatively rigid body, because of their much higher stiffness compared with the ground storey (the displacement of the first floor was about 80% of that of the the top floor). Accordingly, the model was simplified by replacing the three upper storeys with an equivalent concrete massive block which, together with the components connecting it to the second storey, was designed so as to have the same weight, center of gravity and polar moment of inertia as the storeys it replaced.

Additional concrete masses in the first two storeys simulated the dead load of the floors according to the similitude rules and diagonal steel bar stiffeners were used in the second storey, representing the exterior walls in the prototype. In the assembly process connecting elements were cast in situ, special care being taken to ensure full continuity between all storeys.

The microconcrete mix, designed so as to have mechanical properties similar to those of the prototype concrete, had an average compressive strength of 30 MPa. The reinforcing bars were heat-treated 2mm drawn steel wires, again with properties similar to those of the 14mm mild-steel bars of the prototype: 287, 312 MPa yield and tensile strength, respectively, and 32.6% elongation at rupture. The reinforcement of the models included aseismic measures, such as additional stirrups in the ground storey columns, and special horizontal ties connecting the beams with the end columns.

RETROFITTING TECHNIQUES

Two techniques were tested, namely: a) strengthening of the cracked region of all ground columns by tightly fitting metal sleeves with pressure-injected epoxy underneath, using the BICS* method (Models 5,6, Fig. 3), and b) attaching storey-height precast concrete wing-walls to one side of each end ground columns, using epoxy mortar and tie bolts (Model 7, Figs. 4,5).

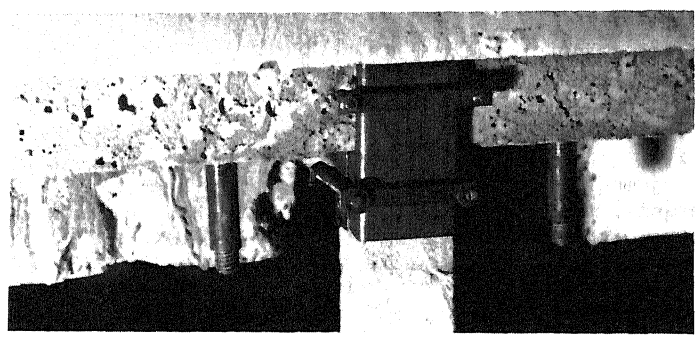

Fig. 3 - First retrofitting technique using metal sleeves and pressure-injected epoxy underneath.

RESULTS AND DISCUSSION

The tests described above showed that the initial pre- and post-retrofitting dynamic properties of the models, namely the natural frequency and critical damping ratio, change with increasing El Centro excitation: generally, the frequency decreased while the damping increased considerably, especially after the cracking stage.

*Balloon Injection for Concrete Structures

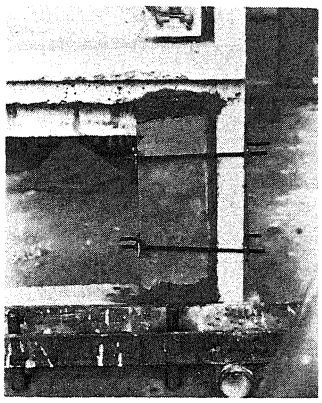

Fig. 4 - Second retrofitting technique using wing-walls.

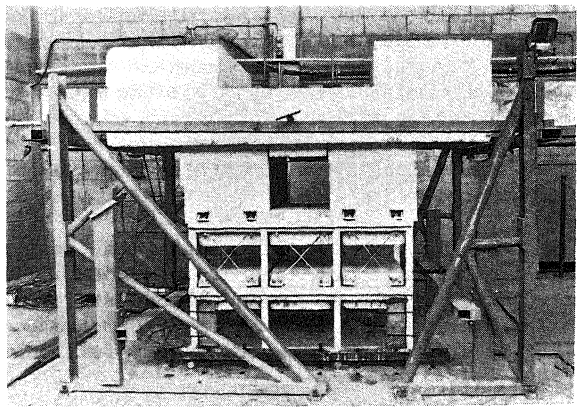

Fig. 5 - General view of Model 7 after retrofitting, and before testing.

The initial properties and original strength level of the models were restored and even enhanced after retrofitting, thereby imparting improved dynamic behaviour. This was demonstrated by the fact, in the retrofitted models, that both the cracking and damage stages set in at higher excitation compared with their original counterparts, depending on the retrofitting technique. For instance, for the metal-sleeve variant the cracking and extensive damage stages were: Model 5 - 0.13g, 0.22g before retrofitting, and 0.17g, 0.28g after retrofitting; Model 6 - 0.14g, 0.17g before, and cracking at 0.16g after (the damage stage could not be clearly defined, because of an unintentional jump in the load during the test). On the other hand, for the wing-wall variant (Model 7) the cracking and damage stages set in at 0.10g, 0.16g before retrofitting, and at 0.32, 0.80g after retrofitting, respectively.

The ground acceleration Ag during the various tests and the models' net top roof acceleration response Ar (Ag deducted) were recorded and analysed for the uncracked and

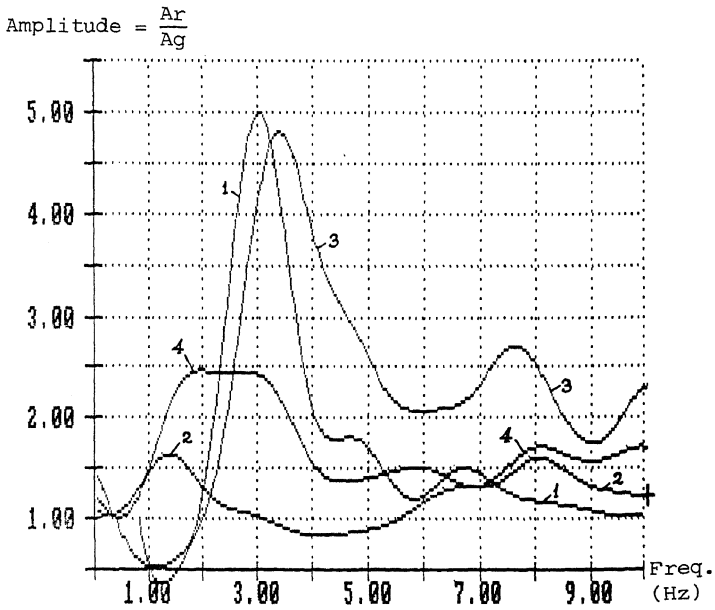

Fig. 6 - Frequency response functions for Model 5.
Curves 1,2 - Before retrofitting at 0.11g (pre-cracking stage) and 0.22g (post-cracking stage)
Curves 3,4 - After retrofitting at same accelerations.

cracked stages before and after retrofitting. The ratio Ar/Ag of the transformed accelerations yielded the corresponding frequency response functions (Figs. 6,7). The uncracked stage is characterized by a peak curve, clearly indicating the actual natural frequency of the model, as well as its critical damping ratio (according to the sharpness or breadth of the peak). On the other hand, the cracked stage is characterized by a flattened curve with a high damping ratio: the flatter the curve - the closer the model to failure.

The efficiency of the retrofitting technique is clearly demonstrated by these curves, when compared to each other for the corresponding stages.

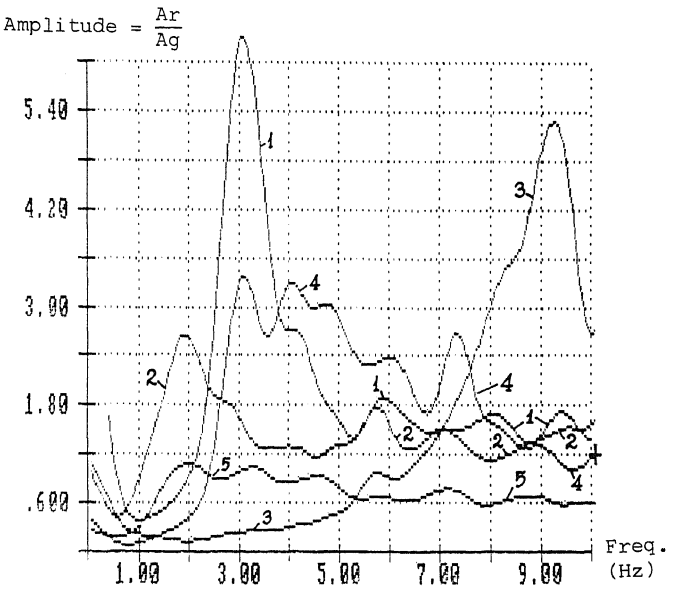

Fig. 7 - Frequency response functions for Model 7.
Curves 1,2 - Before retrofitting at 0.05g (pre-cracking) and 0.16g (post-cracking)
Curves 3,4,5 - After retrofitting at 0.07g (pre-cracking), 0.32g (post-cracking) and 0.80g (extensive damage).

CONCLUSIONS

The conclusions drawn are as follows:

1) Buildings with an open ground storey, in which the ground column-beam joints are mainly affected by seismic action, may be retrofitted and their original dynamic properties and original strength level restored, even enhanced.

2) The efficiency of the retrofitting technique was evaluated experimentally on models by comparing their frequency response functions before and after retrofitting. Tests have shown quantitatively the efficiency of the wing-wall variant, as compared with the metal sleeves variant - a fact already obvious qualitatively.

3) Retrofitting techniques can also be used as aseismic prevention measures in existing undamaged buildings. To this end, recommendations and field instructions should be formulated on the basis of tests on full-scale joint specimens.

ACKNOWLEDGMENT

This research project was sponsored by the Israel Ministry of Construction and Housing.

REFERENCES

[1] Adin, M., Rosenthal, I., Yankelevsky, D. and Itskowitz, M., "Earthquake Response of Apartment Buildings with Open Ground Storey", EUROBUILD '87 - Proceedings, Inter. Conf. on Design and Repair of Buildings in Earthquake Zones, Dubrovnik, Sept. 1987, pp. 122-129.

[2] Endo, T., et al, "Practices of Seismic Retrofit of Existing Concrete Structures in Japan", 8 WCEE Proceedings, San Francisco, 1984, Vol. 1, pp. 469-476.

[3] Mihailescu, M., Olariu, I., Poienar, N., "Restoring Process of Earthquake Damaged Buildings", Housing Science, Vol. 9, No. 3, 1985, pp. 197-204.

[4] Hirosawa, M., "Criteria on the Evaluation of Seismic Safety of Existing Reinforced Concrete Buildings", U.S./Japan 2nd Seminar Proceedings on Repair and Retrofit of Structure, Dept. of Civil Eng., The University of Michigan, May 1981, pp. 49-108.