EXPERIMENTAL AND ANALYTICAL INVESTIGATION OF PREFABRICATED LARGE PANEL SYSTEMS TO BE CONSTRUCTED IN SEISMIC REGIONS

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SUMMARY

This paper presents a concept for study, analysis and research with analytical and experimental investigation of one of the current structural systems being constructed in Yugoslavia. This type of structures, and prefabricated structures generally, are constructed in large series which imposes the seismic risk as a primary factor affecting their stability and damagebility level. The paper includes the main results obtained by extensive investigations of the prefabricated large panel "Rad" system, carried out during the last five years and for which in collaboration with the Berkeley University tests on three-storey models on a seismic shaking table have been carried out. Presented in this paper are the results of the quasistatic tests of connections and three-storey models.

INTRODUCTION

As a result of the increasing demand for residential facilities in Europe after the Second World War, construction of residential buildings in prefabricated structural systems has been widely applied. Nowdays, panel structures are constructed not only in Europe, but all over the world, while production and assembling technologies have been permanently developing, resulting in an efficient and rapid construction and decrease in cost. The construction of prefabricated structures in modern precast structural systems should be 5 - 15% cheaper compared to the traditional way of construction, which depends upon the degree to which finishing is incorporated in the prefabricated product. Reduction in cost, however, is highly dependent upon volume, continuity of production, concentration of demand and type of modular design system, which is closely related to the production technology.

Development of panel structures is related to the production technology and the structural system depending on the type of the system and especially on the connection system.

From structural aspect, the development of production technology and assembling of the panel structures, significantly influences the structural system, i.e., the panel as a member in the system, as well as the connection system of the panel members in general, which considerably increases the need for inves-

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tigation of the stability of these prefabricated systems, especially when subjected to:

- effect of local explosions (in and out of the building),
- soil settlement, as a result of different effects,
- wind effect,
- earthquake effect.

The experience with these structures shows that a risk of progressive collaps should be considered in case of local damages or failure when generally two alternative solutions are suggested:

- To construct the structures in a way so that to avoid the risk of local collapse - damage, which means to have structures in elastic range.
- To allow local damage in the system, but to design the system against collapse (total or partial).

In the case of application of panel structures in seismic areas we can talk of the concept of construction of buildings which would suffer partial damage, i.e., only nonlinear deformations. Thus, the concept of construction of large panel structures is defined on the basis of the behaviour of the structural and the connection members in linear and nonlinear range with defined stress and deformation values according to the explained criteria.

DESIGN CONCEPT

The application of prefabricated panel systems in seismic areas requires a special design approach, with experimental and theoretical studies of the stability of the connection elements and the system as a whole. The involved problems may be summarized as follows:

1. Wall panel elements: rigidity, deformability, strength capacity, reinforcement.
2. Horizontal diaphragm: strength capacity, connection between horizontal and vertical members in the system.
3. Connection system with the following characteristics:
   - bearing stresses at connections,
   - shear transfer through joints,
   - mechanism of energy dissipation,
   - bond characteristics and capacity in connections.
4. Structural layout considerations.
5. Determination of the mathematical model of the system.
6. Analysis: static and dynamic, linear and nonlinear.

The rational construction of prefabricated structures requires production of one type in large series of several thousands per year, which also requires special treatment and study of the seismic risk.

In addition to seismic investigation of the site planned for construction, for definition of the seismic parameters (intensity, frequency content) seismic risk assessment for design purposes should be performed applying a nondeterministic approach.

On the block diagram, presented in Fig. 1, it is shown the design criterium for design of prefabricated panel structures. According to its intensity, the seismic effect is classified into three levels, with the following criteria applied for each:

Level I - for seismic effect of smaller intensity, which occurs frequently, the structural vibration should be controlled in a way that the floor displacements do not cause human desturbance or discomfort.

Level II - for severe, or so called design earthquakes, the structural behaviour is mostly in linear range, but the possibility for nonlinear deformations - cracks in the connections (openings of existing "shrinkage" cracks) of the prefabricated members is not excluded, but with strictly controlled stress values and deformation (storey drift).

Level III - in disastrous and very rare earthquake, structures experience considerable damage - nonlinear deformation, characterized by opening of vertical and horizontal connections, yielding of reinforcement in vertical and horizontal connections, but the structure should not collapse.

MODELLING CONCEPTS FOR ANALYSIS AND EXPERIMENTAL INVESTIGATION

The prefabricated large panel structures differ from those cast-in-place monolith structures. It is known that there is a reduction in strength and rigidity at the connections, and beside that, due to technological and economical reasons the quantity and distribution of reinforcement is completely different. Therefore, it is necessary to find out the places of potential nonlinear hinges and zones in the system, in order to provide proper mathematical model formulation of the structural system.

In most of cases, to simplify the analysis procedure the following assumptions are made for model formulation:

- the panels remain always in linear range,
- all nonlinear nonelastic deformations occur in the zones of connections
- the horizontal panel systems (slabs) are always rigid. The connections in plane between the ceiling members are always in linear range,
- basement and foundation structures remain always rigid.

These basic assumptions provide technically developed and rational analysis giving reliable results with respect to the actual response of the system to seismic effects.

These assumptions for analysis of the system can be accepted only under the condition that the structural system is constructed in a way that in linear and nonlinear range it behaves according to the above assumptions, and if it is not the case, the conclusions of the analysis will apply to the input model which does not represent our system. For this purpose it is necessary to carry out experimental investigations which will define our model with respect to strength and deformability to total collapse.

Investigations are carried out on:

- connection members: vertical and horizontal, and connection members of slabs in plane,

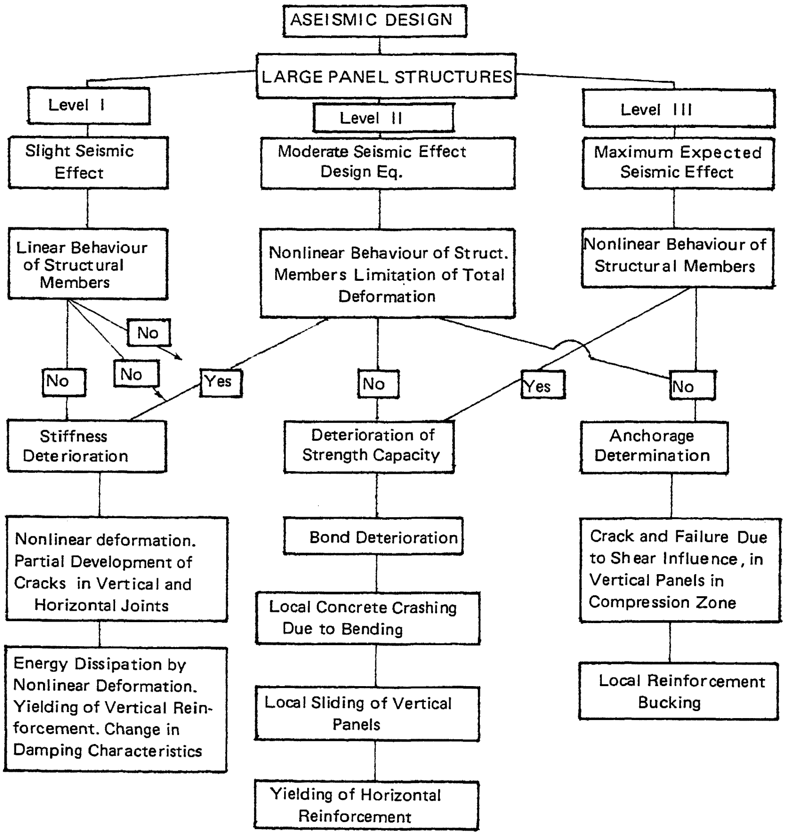

Fig. 1.

- structural fragments: most frequently three-storey models of panels with connections, and possibily parts of structures.

Investigation of quasi-static, cyclic loads and/or tests on a shaking table for dynamic harmonious, or better say, random dynamic effects, can be carried out.

- Forced vibration full-scale testing of structures in linear range, to define the dynamic characteristics etc.
- Testing of structural members in full-scale or model scale under dynamic forced vibration up to collapse, to define the strength and deformability characteristics, in ultimate range.

The experimental technique enables formulation of a real model of the system with defined mechanisms of nonlinear behaviour as dependent upon the seismic effect: the intensity and frequency content of the design and maximum expected earthquake.

Such extensive experimental and theoretical investigations, which can be considered as rather costly ones, having in mind that prefabricated structures are constructed in large series systems, for which special technology and equipment is required, are still completely justified, and practically do not add to the cost per appartment, because the series amount up to several thousands of units per year.

DESCRIPTION OF MODELS AND TEST PROCEDURE OF SYSTEM "RAD"

A ten-storey panel structure, with characteristic plan, was selected as a prototype, considering three characteristic walls: PZ-I-SP 1,2, a panel wall with rectangular section; a wall with openings PZ-II-SP 1,2; and a wall with flanges PZ-III-SP 1,2. Each wall model is constructed of two identical elements in the geometric scale 1:3 with the characteristics and proportions as shown in Fig. 2. The panels were constructed at the production plant, while assembling and casting was performed at the Laboratory of the Institute of Earthquake Engineering and Engineering Seismology, Skopje. The characteristic connections of the modified system are given in Fig. 3.

The modles were loaded in horizontal position by three hydraulic actuators and supports (Fig. 4) simulating axial loading and horizontal cyclic loading. Internal and external instrumentation, an automatic test control system and a processing computer system for data acquisition provide reliability of the results and assessment of failure mechanisms.

Each model of wall is constructed in two, i.e., three identical elements, the first two models were used for pseudo-static cyclic loading (the obtained results have been presented in this paper) while the third model was constructed for testing on a shaking table in Berkeley Laboratory, USA.

Rectangular panel walls - The first element of the rectangular wall models (Fig. 2a) was loaded with nominal axial pressure σ = 0.83 MPa, and variable shear force according to the program for full cyclic loading. It was obtained the hysteretic relation P-Δ (as shown in Fig. 4a), and the LP 211-231 is failure through the tensile reinforcement of the concrete, as displacement ductility of $D_u \simeq 5.0$. On the basis of the obtained relations for force P-gap (Fig. 4b) and shear force R-slip (Fig. 4c) along the fixation contact line and the connection of the prefabricated and cast in situ concrete, as well as according to the failure mechanism and the behaviour of the element, it can be concluded that the initial cracks develop at the floor height of the panel, while in the postelastic stage accumulation of deformations and localization of damage in the contact zone occurs, which increases with increase in the depth of the inelastic range.

The second element of the same model was loaded by nominal axial pressure σ_o = 3.5 MPa, exciting the lower floors of the prototype. The P-Δ hysteretic relation, shown in Fig. 5 compared to that one of Fig. 4a, points clearly to the importance of the axial pressure as one of the factors for decreased deformability and energy absorbtion capacity, as evaluated through the hysteretic relationship

Panel walls with openings - Walls with openings, which by coupling beams enable control of failure mechanisms, are of particular interest for behaviour of large panel structures under actual seismic effects. In order to control such behaviour vertical ties, along the line of the opening (Fig. 2b), and diagonal reinforcement of the coupling beams is introduced. The hysteretic diagram of the first element (σ_o = 1.0MPa) is shown in Fig. 6.

It shows sufficient hysteretic behaviour with displacement ductility larger than 5, separate accumulation and concentration of deformations and damages at the contact zone.

Discussion and results - The obtained results, as briefly presented through

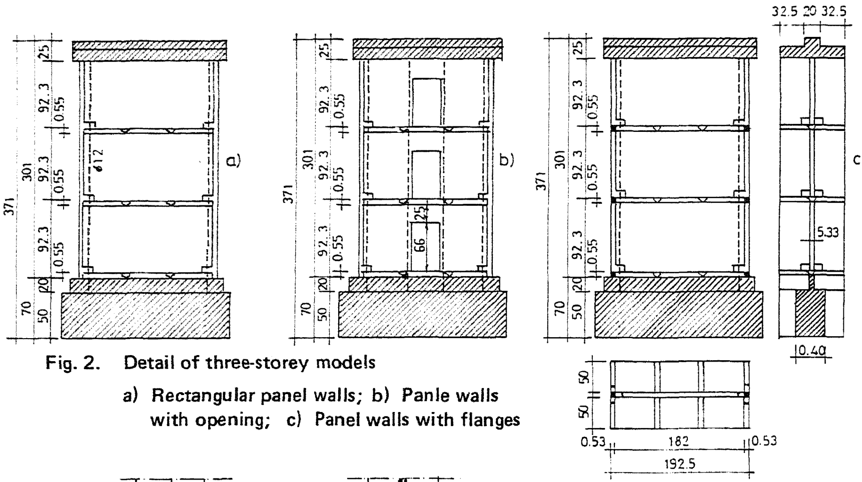

Fig. 2. Detail of three-storey models
a) Rectangular panel walls; b) Panle walls with opening; c) Panel walls with flanges

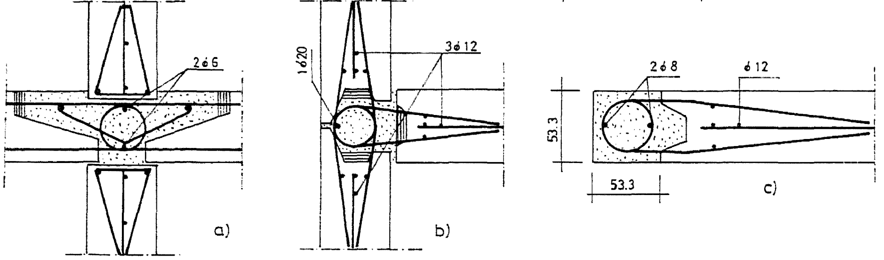

Fig. 3. Detail of monolithic connections. a) Horizontal connection of vertical panels and floor slabs b) Vertical connection of vertical panels with flanges, c) Vertical connection of rectangular panel walls

the characteristic relationships, show that the large panel systems, with carefully designed details of connections, allow their application is seismic conditions, which is estimated by their load carrying capacity and deformability in inealstic range and the ability for energy absorbtion and dissipation.

The characteristic mechanisms of behaviour of precast panels, stated at the beginning of this paper, have been fully proved by experimental investigation and point to the needs for adequate modelling of this type of structures, so that the established relationship only through moment-curvature M-ϕ, or shear distorsion θ-γ and others do not reflect the acutal state, due to the considerable effects of gap openings and slip along the contact zone of the horizontal connection.

Although in modification of the connection system special attention was paid to avoiding the unfavourable shear effects by introducing monolithic stoppers at the sides of the panels, possible brittle failure due to shear has been avoided, however shear slip effect is still predominant within the total shear deformation.

Fig. 7 and Fig. 8 present schemed diagrams for an assembly of panel walls which give characteristic force-displacement relationship points and can be used for dynamic response analysis.

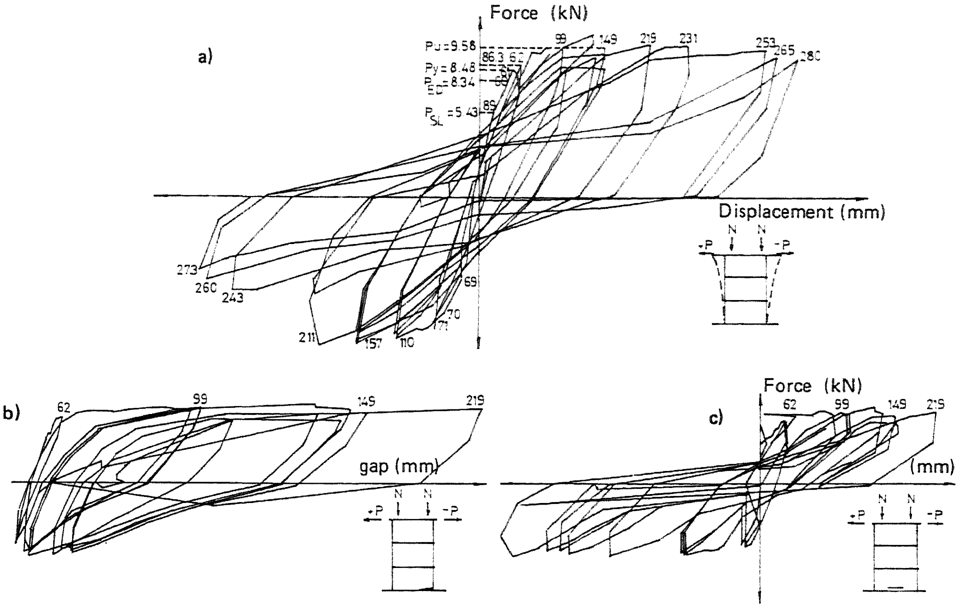

Fig. 4. Rectangular panel wall PZ–I–el. 1 : a) Experimental P–Δ relation; b) Force-gap relation; c) Force-slip relation

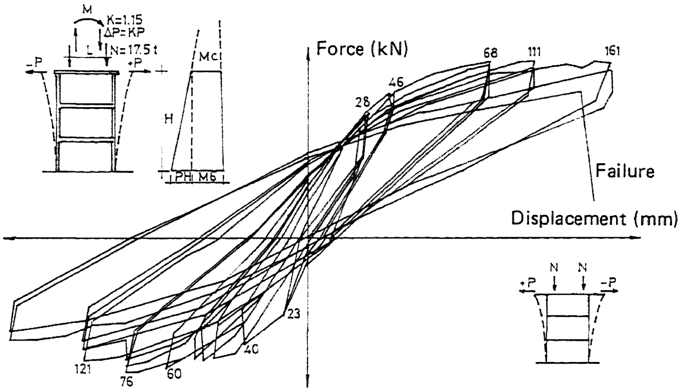

Fig. 5. Force-top deflection relation : P–Δ, PZ–II–el. 2

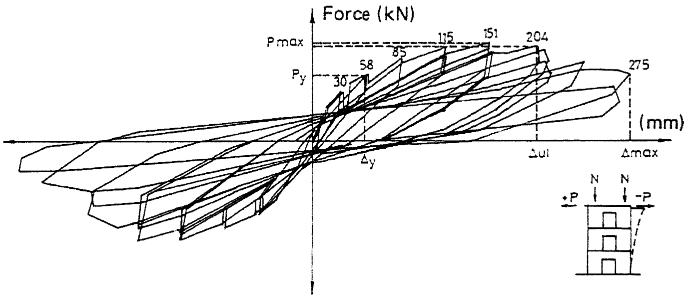

Fig. 6. Walls with openings, PZ–II–el. 1, P–Δ relation

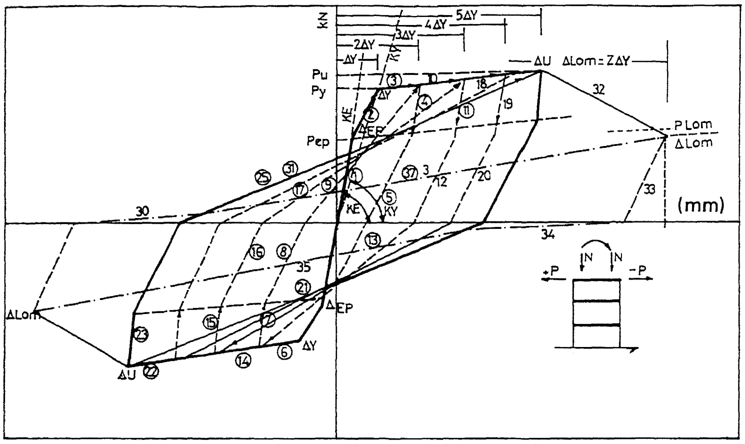

Fig. 7. Schematized hysteresis relationship of the precast panel walls

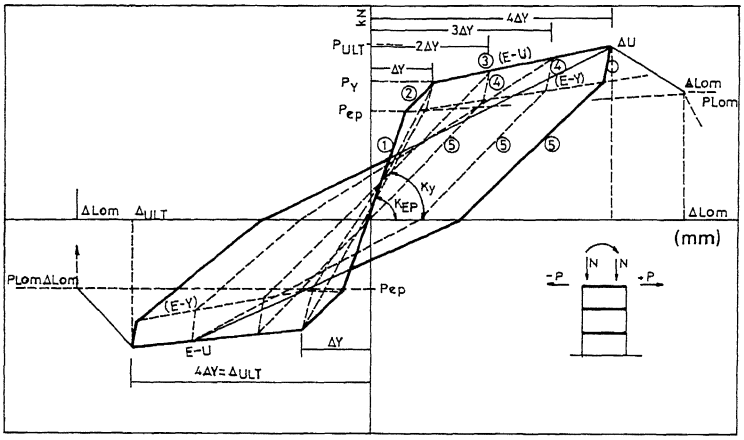

Fig. 8. Schematized hysteresis relationship of the precast panel walls with high vertical forces

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