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EXPERIMENTAL INVESTIGATIONS PERFORMED FOR FRAGMENTS OF LARGE-PANEL REINFORCED CONCRETE SYSTEMS

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ABSTRACT

Within the frameworks of the procedure for analysis and design of stable and economic large-panel reinforced-concrete systems for construction in seismically active regions, with controlled ductile behaviour of the constituent elements and the systems as a whole, up to ultimate strength and deformability states, the results of the experimental investigations have provided the safest way of definition of strength, stiffness and deformability capacity as well as seismic energy dissipation ability, i.e., prediction of the behaviour of bearing structural systems exposed to gravity and seismic-repeated cyclic loads. Experimental investigations of two-storey fragmens of a prefabricated large - panel structure were performed at the IEEES in Skopje for the purpose of verification of the analytical methods for definition of strength and stiffness characteristics of the elements, the failure mechanisms of the elements and the system as a whole, from the beginning of loading up to failure, under different axial stresses and different percentage of uniformly distributed vertical and horizontal reinforcement in the panels, as well as for definition of the hysteretic models of prediction of the response of bearing structural elements in prefabricated LP R/C systems.

KEYWORDS

Prefabricated large - panel structures, experimental investigations, two-storey fragmens, failure mechanisms, strength and stiffness characteristics, hysteretic telationship force - displacment.

INTRODUCTION

Within the frameworks of the complex programme on Nonlinear Behaviour of Large-Panel Prefabricated Structural Systems, anticipated are also experimental investigations of fragments of large panel structure. The programme of the experimental studies involves four fragments of a large panel structure for the purpose of defining their mechanical and deformability characteristics in order to enable definition of the strength and deformability characteristics of the structure. So far, in the practice of design and analysis of large panel systems under static and dynamic loads, the vertical wall panels have been reinforced by a relatively high percentage of vertical and horizontal reinforcement, often with a noncontrolled mechanism of behaviour up to ultimate strength and deformability states. The analysis of the results from the experimental investigations show that the amount of minimal reinforcement in the vertical wall panels, as well as the reinforcement at the ends, and especially the uniformly distributed vertical and horizontal reinforcement, are not always su fficient enough to satisfy the strength and deformability requirements and ductile mechanism of behaviour of the panels up to ultimate strength and deformability states, especially at higher storeys, with significantly low normal stresses. The results from the experimental and analytical investigations will contribute to the definition of the optimal percentage of reinforcement in the vertical wall panels that will be incorporated in the regulations for construction of LP R/C systems in seismically active regions. This considerably decreases the cost of vertical wall panels, without changing of their mechanism of behaviour and decreasing of the structural stability under gravity and seismic loads.

EXPERIMENTAL INVESTIGATIONS

The main objective of the experimental investigations is definition of the main strength and deformability characteristics of the vertical wall panels and proving of their ductile mechanism of behaviour.

The programme of the experimental studies involves four fragments of a large panel structure. The models have two storeys and are constructed to a scale of 1 : 2. The panels have the proportions of $b/d/h = 8/210/132$ $[cm]$, and are reinforced at the ends by $1 \varnothing 12$ (plain reinforcement GA 240/360). The models are constructed as two-storeys models in order to simulate a corresponding moment and shear force in the lower panel.

- Model **FKPZ-M-1** represents a two-storey wall composed of two vertical panels, two horizontal joints and a foundation. The wall panels are reinforced by two reinforcing fabrics $Q-131$ (MAG 500/560), i.e., reinforcement $2 \varnothing 5$ [mm] at a distance of $t = 15.0$ $[cm]$, in both orthogonal directions (Fig. 1). The model is loaded with axial force $N = 360.0$ $[kN]$, i.e., $\sigma_o = 2.14$ $[MPa]$, which simulates a wall with eight storeys above the fragment.

- Model **FKPZ-M-2** is composed of the same elements as model **FKPZ-M-1** (Fig. 1). The model is loaded with axial force $N = 180.0$ $[kN]$, which simulates a wall with four storeys above the fragment.

- Model **FKPZ-M-3** represents a two-storey wall composed of two vertical panels, two horizontal joints and a foundation. The wall panels are reinforced by one reinforcing fabrics $Q-131$ (MAG 500/560), i.e., reinforcement $2 \varnothing 5$ [mm] at a distance of $t = 15.0$ $[cm]$, in both orthogonal directions (Fig. 1). The model is loaded with axial force $N = 180.0$ $[kN]$, i.e., $\sigma_o = 1.07$ $[MPa]$, which simulates a wall with four storeys above the fragment.

- Model **FKPZ-M-4** is composed of the same elements as model **FKPZ-M-3** (Fig. 1). The model is loaded with axial force $N = 360.0$ $[kN]$, which simulates a wall with eight storeys above the fragment.

All the models of precast elements are constructed at the construction site on the basis of a previously prepared project, with reinforcement and shape of prefabricated elements. The models consist of two vertical wall panels, two horizontal joints of vertical panels and a foundation. The equipment for carrying out the experiments consists of equipment for excitation and application of force, electronic automatic equipment for controlling of the experiment as well as data acquisition and data processing equipment.

The equipment for carrying out the experiments consists of equipment for excitation and application of force, electronic automatic equipment for controlling of the experiment as well as data acquisition and data processing equipment. The instrumentation is internal and external. Measured is the input displacement, the input shear force, the input force simulating the gravity load where it is, the relative displacement between the panel which is loaded and the remaining panels and the relative displacement of the loaded panel and the supports, the deformation of the reinforcement at the ends and that of the reinforcing meshes, the elongation and the shortening along the diagonals of the elements (Fig. 2).

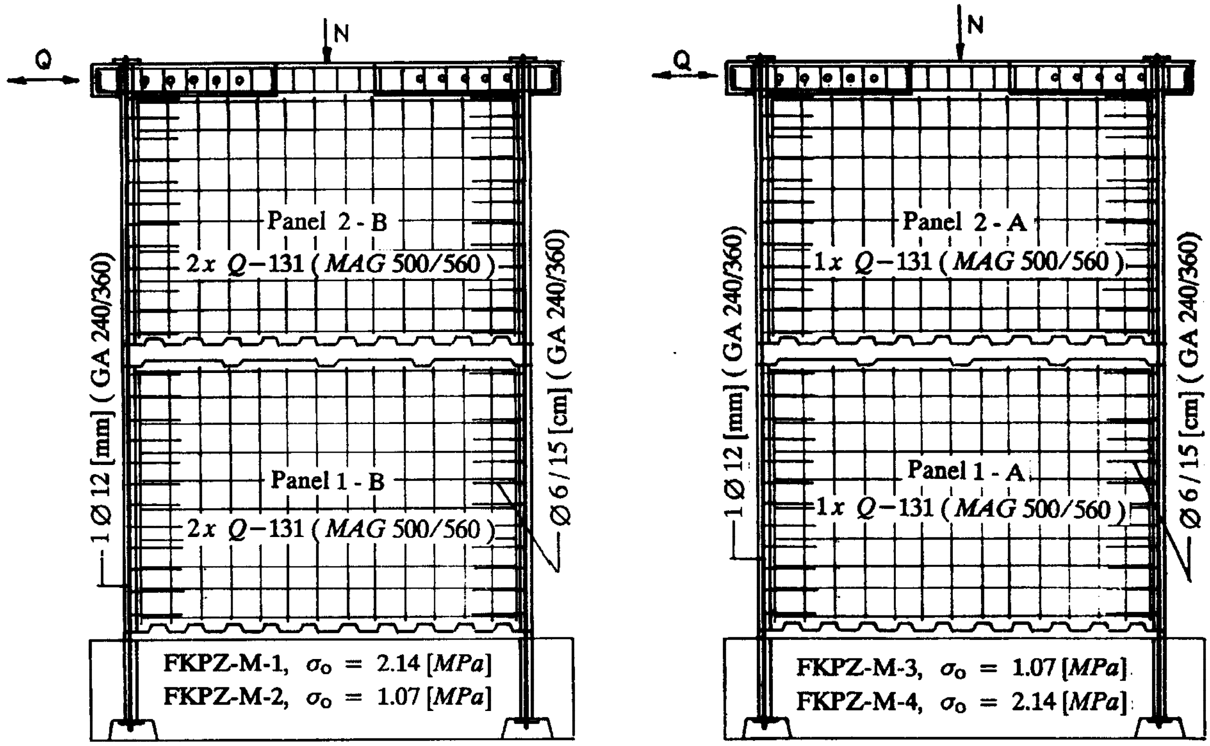

Fig. 1. Detail od the models

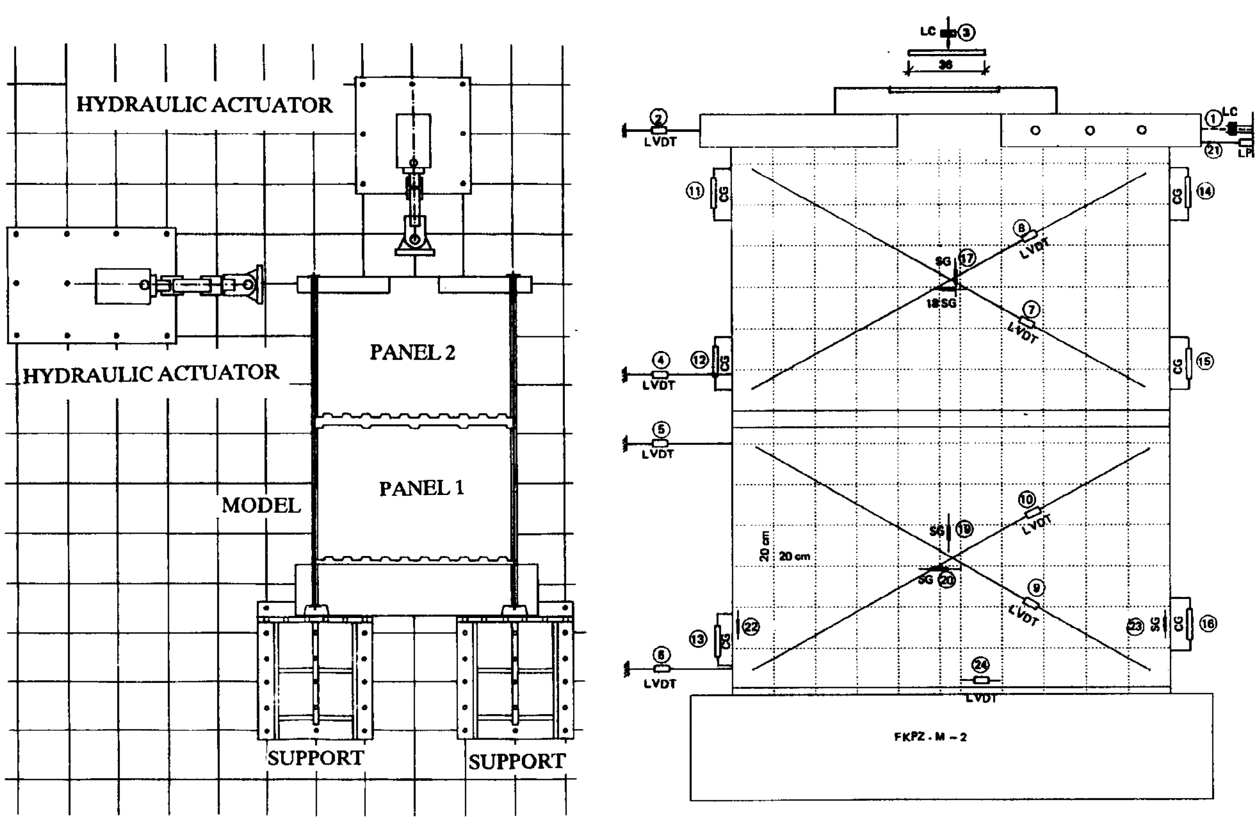

Fig. 2. Disposition of the equipment and instrumentation of of the models

The integral system for automatic control, conducting, measuring and acquisition of data consists of the following: analog system for automatic control of certain mechanical characteristics, a system composed of electromechanic signal converters, the power system for the electromechanic converters and adaptation of the output signals and a system for analog-digital conversion of signals, recording of data and their analysis.

The process of conducting of the experiment is through control of displacement since a relativly big change in displacement occurs by a small change in force. An exception is made in the first three cycles, i.e., at occurrence of the frst crack, where the displacement is very small and it is impossible to be monitored wherefore is controlled the force that is computed for the considered element.

The procedure of conducting the experiment consists of placement of the elements, connection with the actuators of force and the supports, casting-in-place, instrumentation, control of equipment and performance of the experiment. First of all, the elements of the model are placed in a testing position. Using special frames, panel 2 is connected with the actuator of shear and gravity force. Then , casting in place, instrumentation of the model and control of the equipment are performed. First of all, gravity load is applied and is kept constant during the test after which the cyclic load is applied. Reading of the measured quantities is permanent and their values are automatically recorded on a disc and simultaneously visualized on a video terminal For each model, reading was done 246 to 564 times whereat at each reading,. 21 to 24 data were recorded.

RESULTS FROM THE EXPERIMENTAL INVESTIGATIONS AND THEIR ANALYSIS

Realized is a programme of full cyclic loading and obtained are hysteretic force - displacement relationships for different points of the model (Fig. 3 to Fig. 6).

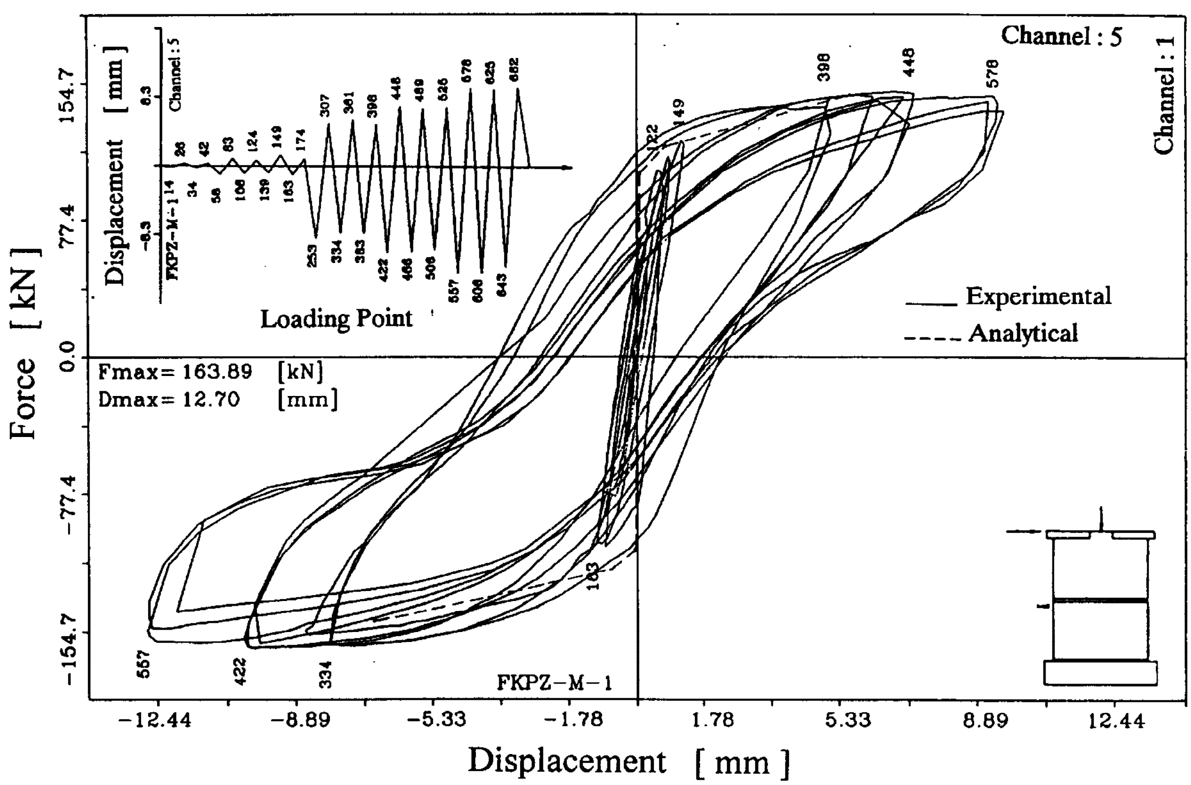

Fig. 3. Hysteretic $P - \Delta$ relationship, Model FKPZ-M-1

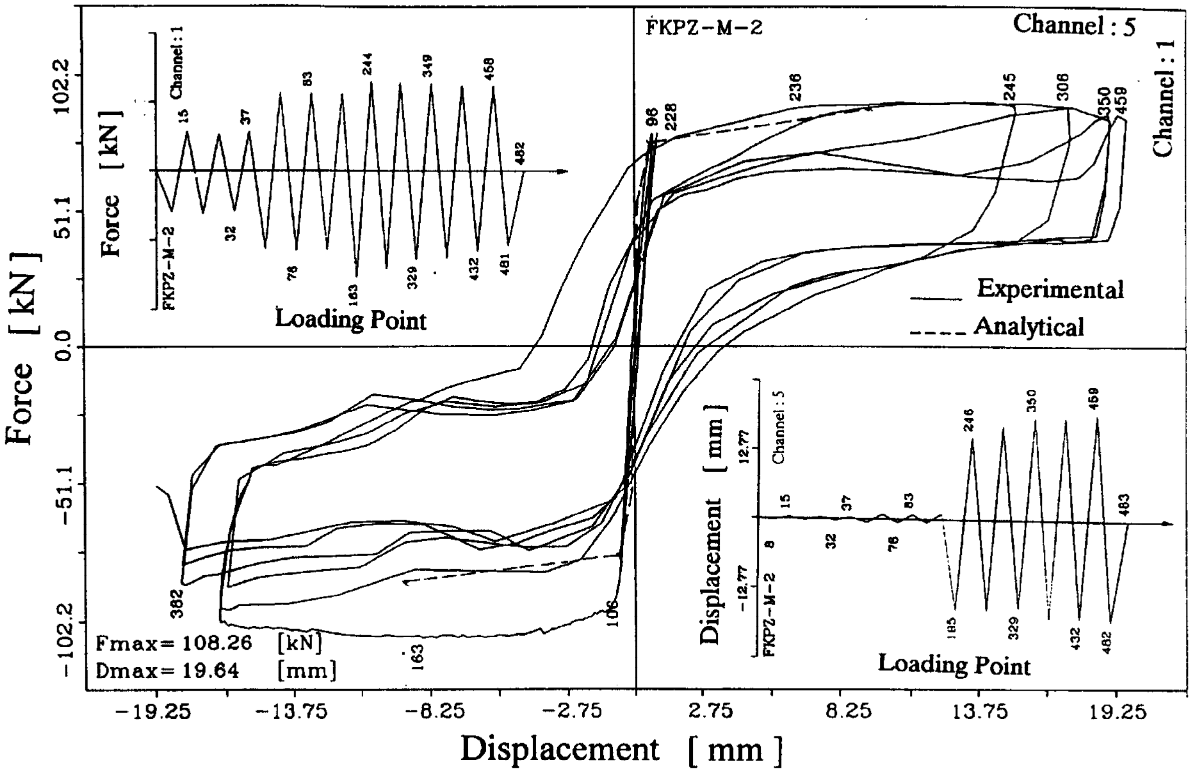

Fig. 4. Hysteretic $P - \Delta$ relationship, Model FKPZ-M-2

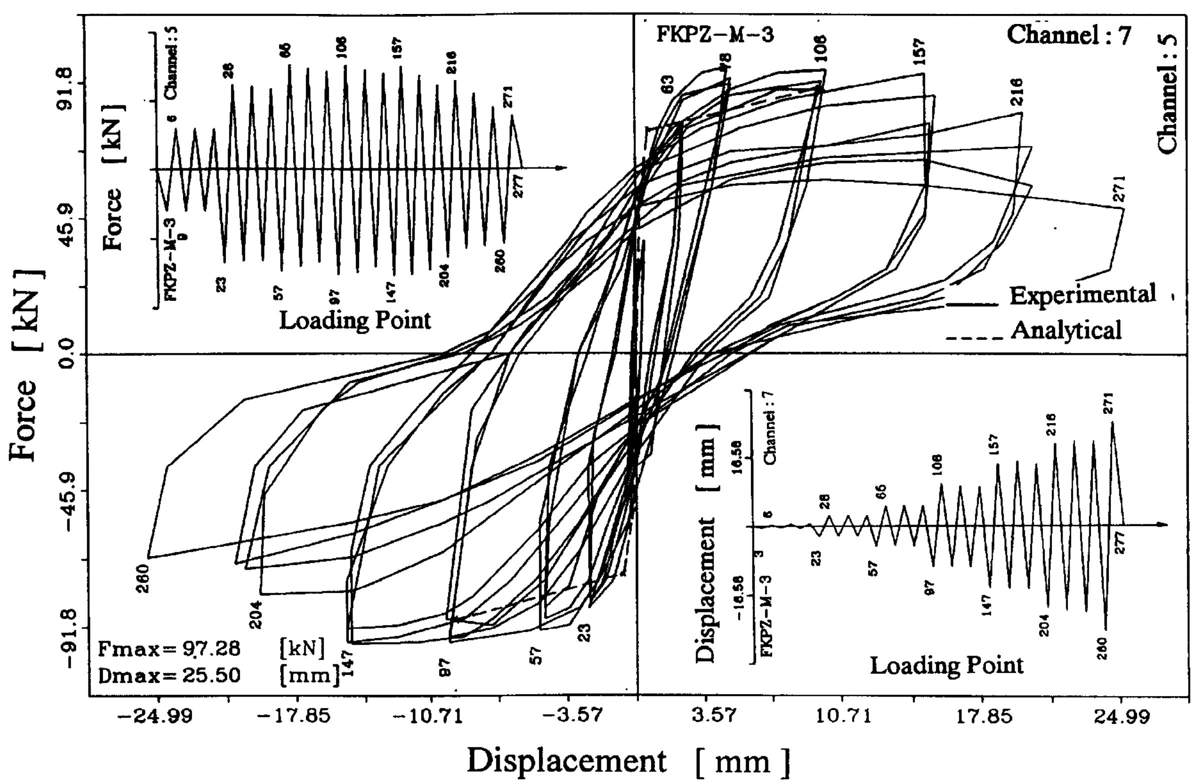

Fig. 5. Hysteretic $P - \Delta$ relationship, Model FKPZ-M-3

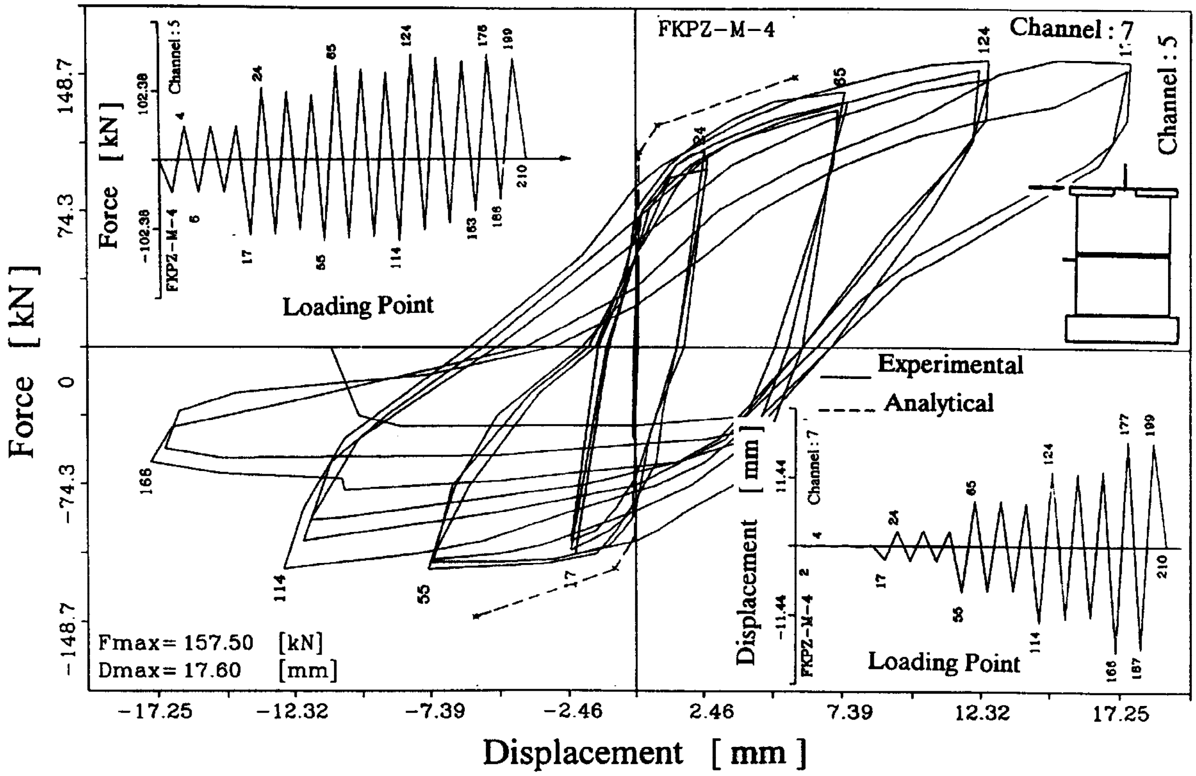

Fig. 6. Hysteretic $P - \Delta$ relationship, Model FKPZ-M-4

The mechanism of behaviour is similar to all four models.

In the beginning of the application of cyclic force, the model works as if the elements and joints are cast-in-place. With the increase in horizontal force, there occur the first micro cracks along the contact surface between the first horizontal joint and the foundation beam. Further increase in cyclic force leads to occurrence of micro cracks in the tensile part of the panel, close to the foundation and yielding of the reinforcement at the ends of Panel 1. At the corners of the panel, next to the foundation, there is an enlargement of cracks up to crushing of concrete which is localized within tens of centimeters.

Even under such large deformations, neither diagonal cracks in the panels nor sliding along horizontal joints takes place. Maximum strains corresponding to stresses in reinforcement amounting to $\sigma_{max} = 12.0 - 15.0\,[MPa]$ were recorded in the uniformly distributed vertical and horizontal reinforcement. This shows that the reinforcement of the panel is far from the elasticity limit, remaining in elastic state even upon reaching of the maximal strength of the panel.

Fig. 7. show the shape and the location of the damages to the models.

The main characteristic of the behaviour of the models are a ductile mechanism of behaviour of the vertical wall panels, with moderate strength and stiffness and a high deformability, i.e., ductility, without diagonal cracks in the vertical wall panels and without sliding along the contact surface of the panels along the horizontal joints. The model has a high initial stiffness and strength in the first phase up to the beginning of large nonlinear deformations which is very close to the bearing capacity of cast-in-place walls and high deformability after occurrence of inealstic deformations. During cyclic loading, there is a drop of stiffness and an insignificant deterioration of strength, inversely variated in respect to the size of inelastic deformations. The denticulated lower contact surface, between the panel and the horizontal joint contributes to the high shear resistance in the joint, without sliding along the contact surface between the panel and the joint. The increase in deformations leads to occurrence of cracks at the ends of the panel, immediately next to the horizontal joint. These cracks run from the panel through the joint up to the foundation beam. The cracks are enlarged with the increase in the amplitude of deformations. This results from the large concentration of complex stresses at the ends of the panel under the effect of axial force, shear force and bending moment. The increase in deformations further leads to opening and closing of the cracks accompanied by slight sliding along the cracks themselves. During this, the reinforcement at the ends is activated via yielding, buckling and disruption. The deformations are concentrated mainly around the first crack between the panel and the joint as well as at the corners of the panel, close to the foundation. No visible cracks are observed in Panels 2 and the second joints.

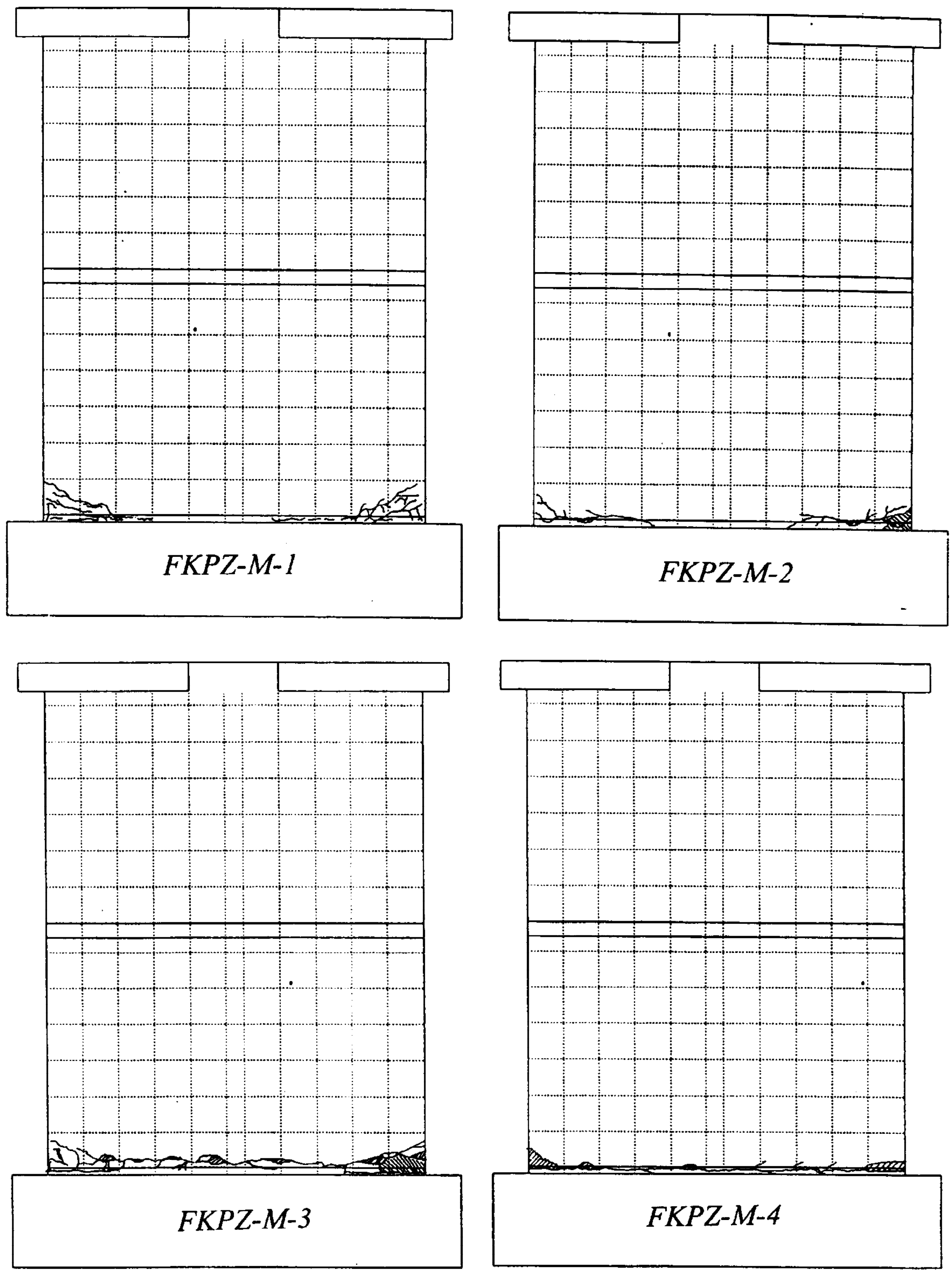

Fig. 7. Shape of cracks

The vertical wall panel behaves in the nonlinear range but with ductile behaviour. In fact, the reinforcement at the ends is activated and a considerable amount of seismic energy is dissipated through its yielding. Crushing of the concrete also takes place at the corners, on a relatively small portion but without diagonal cracks due to main shear stresses.

The main characteristic of the behaviour of the models which have a twice lower amount of distributed vertical and horizontal reinforcement compared to the previous two models, is a ductile mechanism of behaviour of the vertical wall panels, with moderate strength and stiffness and a high deformability capacity, i.e., ductility, without diagonal cracks in the vertical wall panels and no sliding along the contact surface of the panels along the horizontal joints.

CONCLUSIONS

Based on the analysis of the results from the experimental investigations, some conclusions are drawn:

The panels are characterized by a ductile behaviour in all phases, i.e., from the occurrence of the first cracks in the tensile part of the panels next to the contact with the horizontal joint where the bending moment is the highest, through achiving the ultimate elastic limit of the reinforcement at the ends, crushing of concrete at the corners, on a relatively small area, up to failure of the reinforcement at the ends. Damages to the model are concentrated around the initial crack, at the connection between the vertical wall panel, the horizontal joint and the foundation, occurring under low values of force and strain and extending with the increase of displacement amplitude up to crushing of parts of the horizontal joint and the panels. Damages to the panel are minimal and manifaested by crushing of the concrete at the corners next to the foundation, on a relatively small area and yielding up to disruption of the reinforcement at the ends of the panel. Diagonal cracks have not been observed in the panels. The strains in the uniformly distributed horizontal and vertical reinforcement point to relatively low stresses in it, which means that it remains non-activated in the panels. The hysteretic relationships show that the elements have a relatively high ductility capacity, while the displacements are relatively small. This is considered favourabe for the structural response to actual seismic effects. The non-pinched hysteretic relationships point that the model has a high capacity of energy dissipation.

Ductile behaviour of vertical wall panels can be assured by their adequate design, i.e., adequate geometry, reinforcement and position in the structure. The uniformly distributed reinforcement in the panel can be reduced because the behaviour mechanism of the panels shows that damages occur only at their corners, while the reinforcement remains non-activated. In the course of the analysis, there may arise a necessity of a larger amount of uniformly distributed reinforcement to provide safety against main shear stresses. In that case, the panel is reinforced with the required reinforcement.

On the basis of analysis of experimental results for elements loaded with cyclic loads, the shape of the hysteretic force - displacement relationships, the behaviour mechanism, from the beginning of the loading up to failure and damage of elements, for definition of the nonlinear dynamic response of large panel systems, proposed is an original hysteretic diagram with polygonal primary curve and developed is the NALPS computer pgoramme for real seismic effects in which the vertical wall panels, vertical and horizontal joints are included with their strength and deformability characteristics.

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