INVESTIGATION OF STRUCTURAL SYSTEMS AND ELEMENTS IN EARTHQUAKE RESISTANT CIVIL BUILDINGS

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The investigation of earthquake resistant civil building structural systems and their elements was carried out at the TbilZNIIEP during the last years. A solid rigidity core and shifting walls provide seismic stability of tall buildings. Static and dynamic tests of the building models substantiated the design scheme. Seismic-type loads were applied to the full-scale joints. The prefabricated joint rigidity was evaluated by comparison with the solid model. Tests of large-model prefabricated floors solidified by organic and nonorganic binders helped to determine the rigid characteristics of horizontal elements. The results of the investigation of the effective use of prestressing at the construction site are given.

During the last decade new structural schemes of multistorey buildings with rigidity cores as main bearing elements were developed at the TbilZNIIEP. They are vertical walls of closed contour and have a higher rigidity and strength as compared with vertical building elements. The latter may be frames and apart standing walls. The rigidity cores with frame and panel structural schemes, including systems with suspended floors, give excellent combinations. The building structural system consists of two parts: a rigidity core and an annex connected with the core by the floor. This results in obtaining the building dynamic system with an active seismic defence as vibration extinguishers. In the given case the mass of extinguishers is not specially created because the floor disks function as extinguishers. The use of vibration extinguishers in the earthquake resistant buildings makes it possible to lead them out of the resonance in the case of strong earthquakes, to reduce the seismic loads acting on the building, to reduce the building mass and the vibration amplitude. All these phenomena increase seismic resistance of the buildings at small material expenditure.

Various structural systems of the annex (frame, panel and system with suspended floors) require special floor connections with a rigidity core to obtain systems with vibration extinguishers. In the case of the core built around by frame elements the floor disks are joined with the core by means of spring gaskets; as a result we obtain a system with dynamic extinguishers (Fig.1a). If the annex of the core is made of large-panel precast walls, then the floor disks tightly press the core; the precast wall panels are erected on the floor with the elastic material (having increased dissipative properties) in the horizontal joints between them. A system with vibration extinguishers as dampers (energy absorbers) is obtained (Fig.1b). When the building floors are suspended by

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means of cables on the cantilivers arranged on the core top and in the places of the floor disk connection with the core there are small gaps and spring gaskets for their soft co-impact under seismic motions, then the system with impact extinguishers is obtained (Fig.1c).

Three large-scale models of 10- and 12-storey point buildings with the above-discussed extinguishers were investigated in the TbilZNIIEP. Vibration was induced by the inertion-type vibration machine installed on the top of the model.

The first model represented the regidity core in combination with the frame with dynamic extinguishers (Fig.2a). Two stages were investigated: 1 - at the rigid connection of the floor disk with the core and II - at the elastic connection. The dynamic parameters of the model, energy absorption and absolute displacements of the floor disks in resonance conditions were determined. In the case of the elastic connection of the floor disks with the core the displacements showed a 2-3-fold decrease; the stress conditions of the core changed with the decreasing of the tangential and normal stresses in its sections.

The second model represented a rigidity core built around by means of the precast panels with extinguishers as dampers (Fig.2b). Part of the model built around by means of panels was erected on the lower frame floor. The behaviour of the rigid core was studied with and without the annex. It was shown that the pannel annex increases rigidity of the entire building by 30 per cent. Thus it was proved that the panel walls do not receive horizontal loads. The dissipative properties of the buildings increased 4-5-fold. In the rezonance zone the vibrations of the model had small displacement amplitudes.

The third model represented the rigidity core having suspended floors on the cables with impact extinguishers (Fig. 2c). During the test we studied the dynamic parameters of the model and its behaviour in the resonance conditions at different levels of the cable tension and also at the rigid connection of the floor disks with the core and at small and great volume gaps (for finding optimal gap sizes when the vibration extinguishers lead the model out from resonance). The experiments proved that the buioldings with impact extinguishers are not lead into established resonance and the displacement amplitudes of the floor disks are 5-6 times smaller than in the case of rigid connection of the floor disks with the rigidity core.

Besides these experiments on the models we considered rigidity problems and problems of strength of reinforced concrete solid and precast rigidity coreswith normal reinforcement and prestressing of vertical reinforcing bars placed in the open channels along the core perimeter. Different geometrical core sections - rectangular and with continuous sides (Fig.3)- were studied.

For the abovementioned new structural schemes of the buildings with rigidity cores design and mathematical models are worked out and the enginnering method for their design based on the spectral method of earthquake resistance.

In the foreign building practice frame structures with plane slabs without drop panels are widely used. Failure of these structures during the latest destructive earthquakes limited the construction of residential and public buildings with the use of these types of frames. However, the popularity and cost efficiency of the structure made it practicable to investigate the reasons of its failure and to develop recommendations on their elimination.

In our country where residential and public buildings are constructed mainly by industrial methods the problems of assembled prefabricated components joint action are of primary importance and therefore the activity of the research centres engaged in the problems of earthquake resistant construction is directed to the study of these connections. The TbilZNIIEP has developed the solution of the frame structure which is the basis for development of a new version of the unified series. Along with other advantages of this frame structure the solution of mounting problems is of great interes (Fig.4).

Full-scale joint patterns have been tested to solve the given problems. The experiments have been carried out in three series with two specimens in each. The experiments of the 1st series were devoted to the study of the standard solid joint. Joint components were reinforced according to the design data (Fig.5). As it was stated above, the first two samples were cast in-situ and the normative requirement on the 50 per cent of the working reinforcement being passed through the column was considered. The 2nd series samples were made separately and connected afterwards. The "cross-bar column connection" was made by means of a concrete dowel. The samples of the 3rd series were connected with special fixings.

To follow the deformations of the tensile and compressed reinforcement bars a tensoresistor of 30 mm base was installed at specially left points. The deflections were measured with the Maximov defletometer with 0.1 mm division. Concrete deformations were measured with the tensoresistor of 50 mm base. .

The installation allowed to change the direction and volume of loads. The connection or the cross-bar failure should take place at the 317.94 kNm magnitude of bending moment, which corresponds to the 210.0 kN force applied to the crossbar at 150 cm from the centre of the column. The normal force of the column was 1500 kN. in the column.

Solid pattern tests showed that under symmetrical and asymmetrical loading all the bars located in the cross-bar section took part in the element performance (Fig.6).

The 2nd series of tests made it possible to study the behaviour of the assembled connection of the cross-bar threaded on the column. In this case the longitudinal reinforcement remained but the working reinforcement was outside the column, i.e. in a prefabricated cross-bar. The cross-bar was connected with the column by means of a concrete dowel. The connection failed after the second step of loading due to the 180 kNm magnitude of the bending moment (Fig.7). The last series of tests experimentally proved the efficiency of the measures on the connection reinforcement. A particular attention should be paid to the high flexibility degree of the adopted connections (Fig.8). As it can be seen from the diagram "load-deviation" the opposite curves of the hysteretic loop are close enough to each other and bear the likeness to the behaviour of elastic material.

The experiments reaffirmed the viability of "Frames for Civil Buildings" and allowed to develop the recommendation for the connection design of floor slabs without drop panels (Fig.9)

The stiffness and stability of the building in the horizontal plane must be secured by the floor functioning as horizontal disks distributing seismic load among vertical bearing structures. However, it is known that the joints of the prefabricated floors monolized by cement mortar do not secure the joint operation of prefabricated members not only in horizontal but in vertical direction as well.

To secure the solidity and equal stiffness of the joints of the prefabricated reinforced concrete structures turning such floors into stiff disk-diaphragm different adhesive compounds based on organic and inorganic binders were studied at the TbilZNIIEP.

Investigations were carried out on the large-model floor specimens sized 1.30x3.92 m, representing reinforced concrete 3-span bracing with prefabricated reinforced concrete slabs sized 0.24x1.20 m. The monolizing of the slab joints among themselves and with the bracing was performed by epoxy polymer mortar (model M-1), polymer-cement mortar (model M-2) and paste based on water glass (model M-3). Simultaneously the control floor models - monolithic (model M-4) and prefabricated, monolized by cement mortar (model M-5) were studied.

The models of the floors were tested on horizontal-static, cyclic, alternating increasing loads, dynamic vibratory loads and on vertical static load as well .

The static loading was carried out in the every 1/3 part of the span by means of the 100 ton hydraulic jack. A seismic load was simulated by testing the models on thecyclic alternating increasing load by means of the two 100 ton hydraulic jacks and on the vibratory load by means of the vibromachine with mirror-symmetrically located unbalanced masses rotating in different directions. The dynamic characteristics of the models were registered before and after the tests.

The results of measuring deflections, period of natural oscillations and shearing strain of the panels testified to the significant increase of stiffness of prefabricated floors (Fig. 10, Table 1). The bearing capacity and stiffness of the models M-1 and M-2 appeared to be practically equal to those of the monolithic model M-4. The same values of the model M-3 appeared to be less than those of the solid one but almost twofold greater than those of the model M-5.

The obtained results of static and dynamic investigations testify to the fact that the prefabricated floors monolized by epoxy polymer mortars and polymer-cement compounds may be considered as solid disks capable to distribute loads among the vertical bearing structures. Simultaneously, the joint operation of prefabricated slabs in vertical direction is secured.

To the constructive systems capable to give the buildings the required earthquake resistance we may refer the solutions based on a wide application of the reinforcement tightening during the construction process with a purpose of uniting the members of the prefabricated structures.

Along with the development and testing of various constructive members of the buildings and their connections we studied some aspects of the prestressing of reinforced concrete structure used to increase the seismic stability of the designed objects, in particular, by influencing the dissipative properties of the structures.

A possibility was also considered to lessen the probability of resonance phenomena by regulating the value of the prestressing of the reinforcement (uniting the members of the bearing structures). An aim was pursued here to achieve changes of the rigid characteristics of the structures at the given levels of seismic effects produced by shifts in the compressed connections.

In the framework of this paper we give some results of our experimental investigations of the full-scale specimens and large-scale models of fragments of the prestressed structures.

The study of the behaviour of prefabricated prestressed members of the panel-type in which high-strength reinforcement was placed along the contour of the constructive cells (floors, vertical diaphragms of rigidity) has shown that the reliability of such members mainly depends on the susceptibility of stresses, including the shifting ones, along the entire plane of the panel (along the entire length of the joints of the structure). In this case the presence of the compressing forces producing friction forces in the joints may be insufficient which makes it necessary to take up some additional measures such as splines, the grouting of the protruding parts of the reinforcement and so on. In these conditions, naturally, the importance of choosing the optimal construction (the cutting diagram including) of the considered members increases.

In particular, the investigations have allowed us to recommend the construction of floors in the frame-panel buildings of the Yugoslavian system IMS formed in each constructive cell of two panels fixed along three sides with the fourth side being free. The fixing of the panels in the grouting concrete of the high-strength reinforcement along the cell contour is ensured by the splines and protrusions of the reinforcement. The experiments confirmed the presence of essential reserves of the bearing capability of the recommended construction of floors. The surface of deflections of the model of this construction (the scale is 1:2.5) produced by the long-term vertical load (90 days) is shown in Fig. 11.

For the experimental investigation of the prefabricated reinforced concrete vertical diaphragms of rigidity we chose a two-span diaphragm with apertures of a 16-storey building. The modelling of the diaphragm was carried out on the basis of geometric similarity (the scale is 1:6). The wall panels of the model with two apertures were made in the form of 2-storey blocks with width equal to half a panel; the blocks were braced by the horizontal reinforcement which was placed above and under the apertures.

Comparison of the results of the tests of the model with the results of the previous tests of the model of the prefabricated diaphragm with the usual reinforcement and welded joints of the reinforcement protrusions has shown that as a result of the prestressing of horizontal reinforcement the pliancy of the model decreases essentially.

The dynamic tests of the prestressed diaphragms, which are continued at present, confirm the possibility of regulating their dissipative properties.

The researchers of the carcass building laboratory of the TbilZNIIEP P.Garbuzov, T.Janashia and R.Kvantaliani are responsible for the investigation of the models of pre-stressed floors and diaphragms of rigidity.

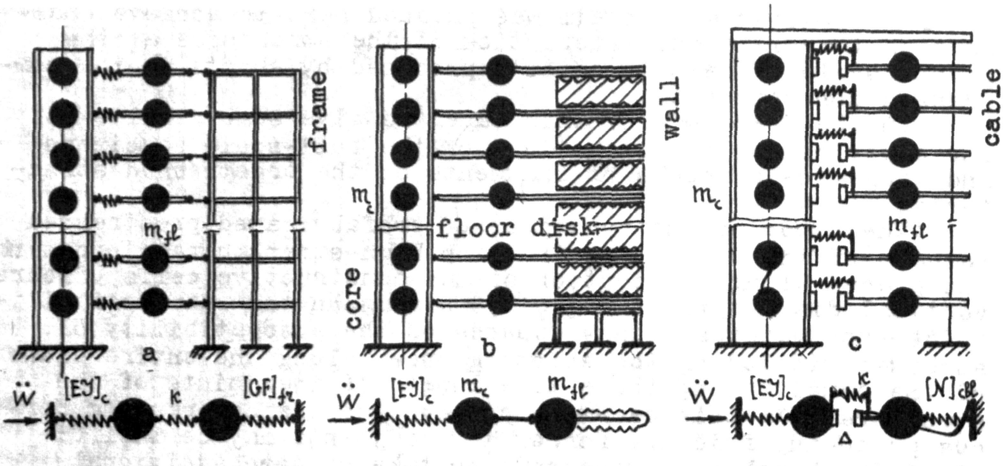

Fig.I Systems with extinguishers: a - dynamic, b - dampers, c - impact

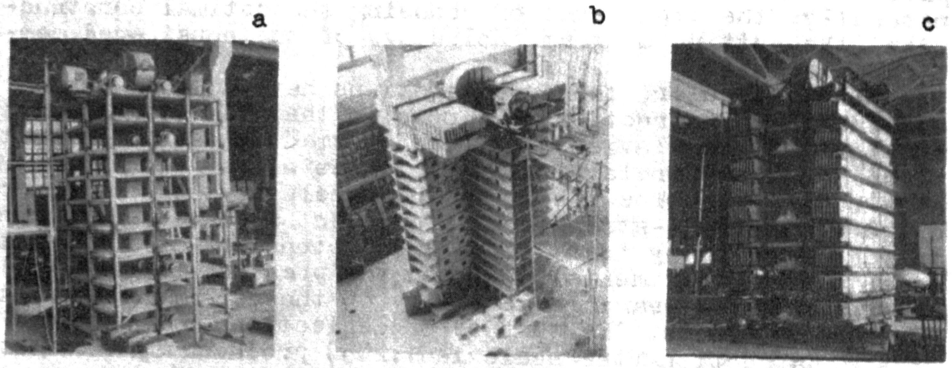

Fig.2 Building model with rigidity cores and annexes: a - frame, b - panel, c - suspended floors

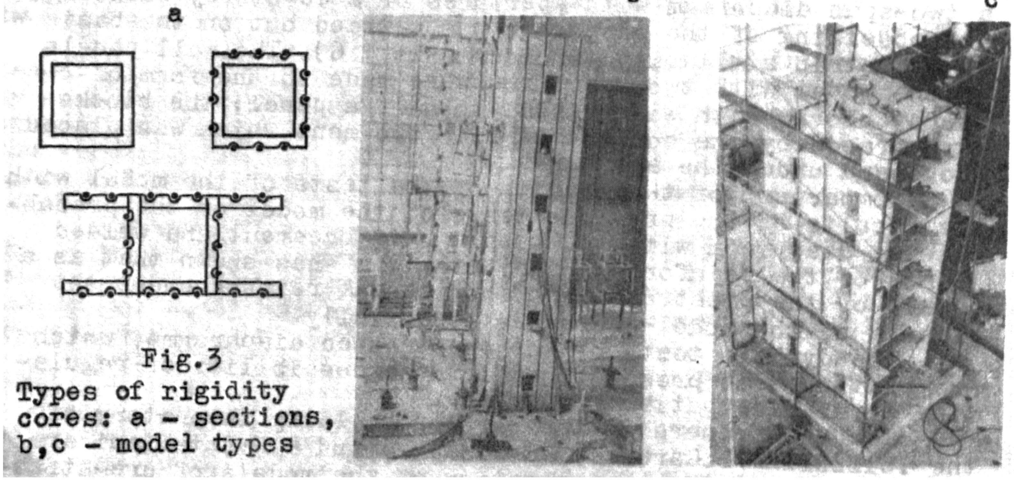

Fig.3
Types of rigidity cores: a - sections, b,c - model types

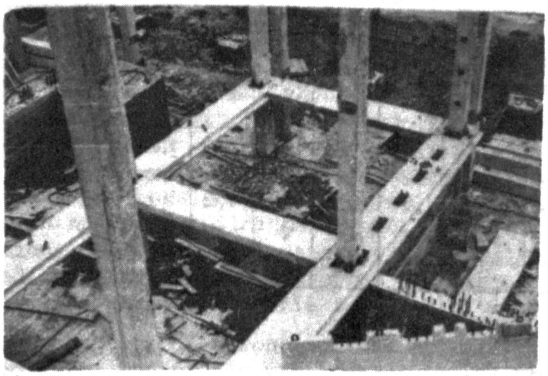

Fig.4 Part of the frame

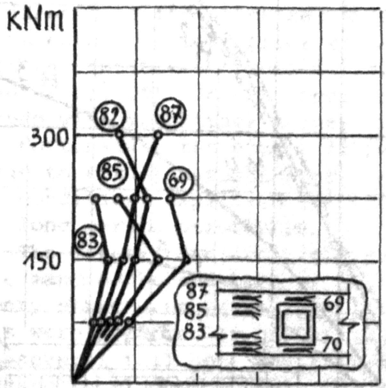

Fig.6 Stress in tensioned reinforcement of the standard joint

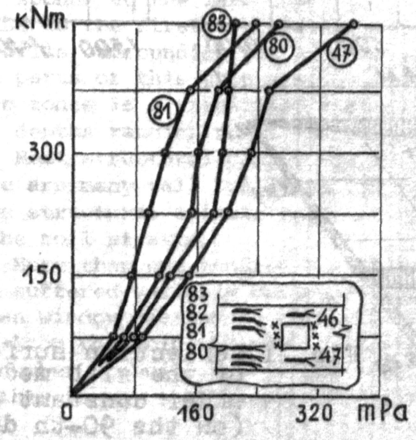

Fig.8 Stress in reinforcement of the prefabricated strengthened joint

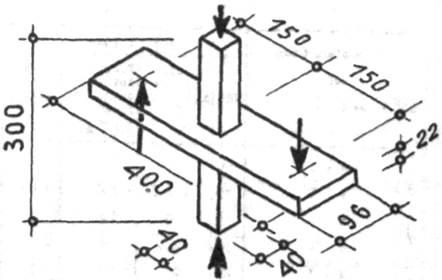

Fig.5 Tested patterns

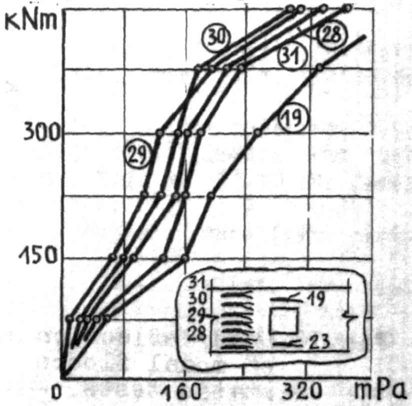

Fig.7 Stress in reinforcement of the prefabricated joint

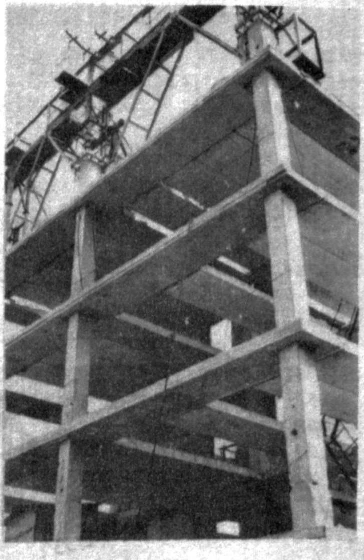

Fig.9 Construction of the I4 story frame building

Results of testing the floors on horizontal load

Table

Designation of models	Static load				Cyclic load				Vibratory load			
	P KH	Monolithic model %	Elastic deflection at IO kH IO^{-4} sm	Given static stiffness	P KH	Monolithic model %	Elastic deflection at IO kH IO^{-4} sm	Given dynamic stiffness	Frequency of oscillation herts	Absorbtion coefficient	Given stiffness	Freq. of destroyed models oscillations htz
M - I	40	IOO	2IO	I	40	IOO	220	I	28	0,69	I,0	9,0
M - 2	45	II2,5	250	0,84	45	II2,5	260	0,85	3I	0,60	I,23	9,0
M - 3	40	IIO	I50	I,4	45	II2,5	I80	I,22	28	0,60	I,00	6,0
M - 4	35	87,5	320	0,78	35	87,5	360	0,6I	I9	0,3I	0,46I	3,0
M - 5	20	50	420	0,5	22	55	440	0,5	I4	0,4I	0,4I	2,9

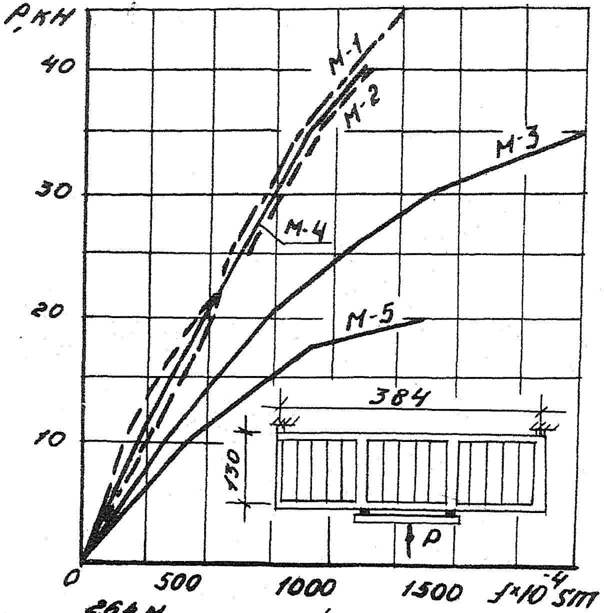

Fig.IO.Load/deflection of model floors static tests.

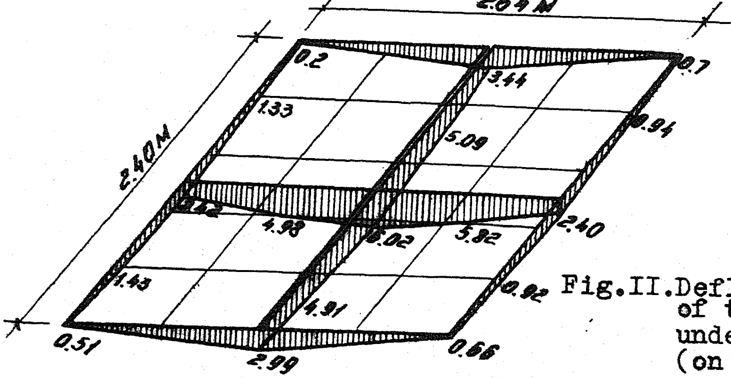

Fig.II.Deflection surface of the slab model under constant load (on the 90-th day)