EARTHQUAKE RESISTANT STRUCTURES OF RESIDENTIAL AND PUBLIC BUILDINGS IN THE USSR

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The paper deals with some problems in the field of investigation and design of residential and public buildings carried out in the USSR for regions subjected to seismic effects. It contains the description of building structures used in large-scale earthquake construction in the USSR. Particular attention is paid to precast large panel structures; some types of joints used in precast structures are described.

1. Regions with seismic intensity from 6 to 9 degrees occupy approximately one-fifth of the whole territory of the USSR. Owing to this, problems of earthquake resistant construction in this country is of great importance for reasons of safety of the population during earthquakes and for economic reasons. On the whole, seismic regions are situated along southern boundaries of the country. The seismicity of regions is approximately as follows (1): 6-degree regions - 54.5 per cent, 7-degree regions - 26.7 per cent, 8-degree regions - 12.4 per cent and 9-degree regions - 6.4 per cent. The increase of seismicity by one degree results in the increase of the total cost of construction of buildings by 2-4 per cent.

2. Design and construction of buildings in seismic regions of the USSR are carried out according to instructions of special building norms which are periodically revised owing to the elaboration of methods of research and construction. At present the norms approved in 1962 are in force (2). These norms contain instructions relating to specific features of designing and calculation of structures with due regard to seismic loads.

The method of calculating seismic loads adopted in this country is based on the estimation of their value as the function of period and form of free vibrations of structures (3). For structures characterized by low damping correction factors increasing seismic loads are introduced. The value of a seismic load depends upon the seismicity coefficient and

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the latter, in its turn, is determined by the design seismicity defined in accordance with the purpose of the structure and the seismicity of the region.

For ordinary residential and public buildings the design seismicity coincides with the seismicity of the region. It is increased by one degree for specially important buildings and is reduced by one degree for buildings the failure of which will not cause casualties or will damage valuable equipment. On the basis of maps of seismic microregioning and the data of geological and hydrogeological surveys it is allowed to more accurately define the seismicity of the building site by its increasing or decreasing by one degree. It is taken into account here that unweathered rocks as well as dense and low-moist coarse-fragmental soils are most favourable soils from the viewpoint of earthquake resistance. Unfavourable soils are saturated gravel, sand and clay (marcoporous) soils as well as plastic and fluent clay (non macroporous) soils.

The general arrangement of buildings designed for construction in seismic regions, the distribution of rigidities of their load-bearing structures and masses must meet the requirements of the symmetry about central axes and the uniformity of the distribution in building plan. In those cases when this requirement cannot be met the calculation of load-bearing structures takes into account additional stresses occurring due to the development of torsional moments in the horizontal plane of a building. Elements of load-bearing structures must be, if possible, of equal strength. When designing metal and reinforced concrete structures measures are provided ensuring the possibility of developing plastic deformations in elements and assemblies. When designing precast structures preference should be given to joints capable of developing elastic-plastic deformations trying to prevent at the same time high concentration of stresses in elements of structures and fragile connections. After the erection precast reinforced concrete structures should be close by their characteristics to cast in-situ reinforced concrete structures.

Earthquake resistant buildings are designed: a) as rigid structures made of vertical load-bearing elements working under the action of seismic forces mainly for shear and characterized by low deformations (period of the fundamental tone of free vibrations is up to 0.5 sec); b) as flexible structures made of vertical load-bearing elements working mainly for bending. When choosing the scheme of a building it should be taken into account that the flexible scheme results in the reduction of the dynamic coefficient while buildings with the rigid structural scheme are characterized by more intensive damping. Table 1 contains average values of periods of free vibrations for rigid buildings with the various number of stories. Close values of periods of free vibrations in longitudinal and transverse directions show the decisive effect of shear deformations.

Depending upon the design seismicity and characteristics of earthquake resistance of buildings the norms specify the corresponding structural restrictions of their dimensions (Table 2) which are obligatory irrespective of the results of the calculation.

3. In seismic regions of the USSR the following designs of load-bearing structures are used for permanent buildings: large panel, large block, frame and masonry designs (the latter with walls erected of brick and natural stones).

From the viewpoint of earthquake resistance and economy preference is given to large panel and frame buildings. Earthquake resistance of the first type of buildings is not checked up by the experience gained during earthquakes and in this case calculation analysis and the data of laboratory investigations are used for grounds.

Large panel walls used for earthquake resistant construction offer the following advantages over heavy walls made of piece stones and brick. First of all, they are characterized by a substantially lower weight which can be seen from the data of Table 3 containing figures per 1 sq. meter of living area. The reduction of the weight of buildings results in the corresponding reduction of seismic loads, this being one of the most important factors of increasing their earthquake resistance. Requirements for the typification of precast products impose simple and clear architectural designs favourable for earthquake resistant construction, this being the second advantage of large panel buildings (Fig. 1). Large panel buildings are rectangular in plan and have the uniform, without the break of axes, and close (2.6-6 m) spacing of transverse walls which, apart from the deconcentration of seismic forces, ensures better conditions for the work of floors - horizontal diaphragms of rigidity of the building. In this case each cell between vertical load-bearing elements is spanned not by several panels, as is required when widely spacing transverse walls, but only by one panel. Experiments have showed that in the case of several precast floor panels in the span between load-bearing walls the rigidity of floors is sharply reduced. The third advantage of large panel buildings is greater guarantee of quality and uniformity of prefabricated panels as compared with the quality of the hand masonry of stone walls. The material of large panel walls (reinforced concrete, vibro-brick masonry) is noted for substantially higher resistance to shear in comparison with piece wall masonry (Table 4). Finally, the availability of vertical and horizontal reinforcement increases the load-bearing capacity of panels and earthquake resistance of the building as a whole.

4. Large panel buildings are mainly erected of thin-walled room-sized panels (internal wall panels are 12 cm thick and external wall panels are 25-32 cm thick depending upon the design and climatic conditions). Panels are made of heavy or lightweight concrete of 200 grade (strength) rein-

forced with two welded meshes or cages. The latter method of reinforcing is more preferable since it excludes the necessity of using special anchors for the connection of panels, ensures the direct transfer of stresses from the reinforcement of one panel to that of the other one, and is more reliable from the viewpoint of ensuring the design positioning of reinforcement. External wall panels are made either as three-layer or solid panels. Panels of the first type are provided with the load-bearing layer (8-10 cm thick reinforced concrete), thermal insulating layer made of lightweight concrete or mineral wool boards and an external layer of 4-5 cm thick reinforced concrete. Both reinforced concrete layers are connected by means of reinforced lightweight concrete ribs. Some designs of internal and external wall reinforced concrete panels are shown in Fig. 2. Floor panels are made in the form of solid 10 cm thick reinforced concrete slabs or 22 cm thick slabs with circular voids.

On a limited scale (for experimental purposes) panels of vibro-brick masonry (internal wall thickness - 14-27 cm) and of vibro-stone masonry (internal wall thickness - 21-22 cm) are used for buildings with the design seismicity of 7-8 degrees. Examples of their designs are shown in Fig.3. Vibro-brick and vibro-stone panels are made with the mortar of 75-100 grade (strength). Such panels are characterized by high compressive strength and bond. Their compressive strength is 2.0-2.5 times higher for brick masonry and 1.2-1.4 times higher for stone masonry as compared with the corresponding piece masonry.

Two types of joints are used for large panel buildings (Fig. 4): cast in-situ (concreted) joints and joints with inserts. Concreted joints are more preferable since they concentrate less stresses and require substantially less steel than joints with inserts. The latter type of joints is still to be used in localities where the lasting winter complicates concreting of cast in-situ joints.

Extensive research, dealing with the strength of panels of various designs, solid and with openings, made of various materials and variously reinforced, has been carried out in this country for studying earthquake resistance of large panel buildings and their elements. Great attention was paid to the study of joints of large-sized panels. Apart from field tests of buildings and laboratory investigations of earthquake resistance of their individual elements for studying dynamic characteristics of large panel buildings, finding out the laws governing the distribution of stresses between various flat elements of large panel buildings (between walls of various rigidities, roofs, etc.) experiments were carried out using models about 1/4 of full-scale dimensions (Fig. 5). Such experiments are carried out on a 25-t hoisting capacity vibro-platform making it possible to develop horizontal vibrations.

5. Frame buildings have undergone severe checking during

serious earthquakes and have shown sufficient safety. Thus, after the earthquake in Skoplje (Yugoslavia) in 1963 many buildings up to 6 storeys high with load-bearing brick walls completely collapsed while frame buildings up to 14 storeys high remained only slightly damaged in the brick cladding.

Frame residential and public buildings are erected with the use of reinforced concrete frame and large panel curtain walling or with solid brick cladding. In the latter case the frame is of a complex type, this providing for the saving of shuttering and greater monolithic character of the structure.

Frame buildings with solid brick cladding and moderate area of openings refer to the group of buildings with the rigid structural scheme (high tower buildings are not meant here). Seismic loads acting on such buildings are high, and if we make calculations for walls neglecting the influence of cladding on their load-bearing capacity, the elements of the frame appear to be unwarrantedly heavy. Experiments have been carried out in this country aimed at investigating the character of the behaviour of frame walls with brick cladding (Fig. 6). The experiments have showed that as the load on the walls increases, the stress state of cladding undergoes some changes. In the first stage of loading the frame and the cladding work together as a monolithic structure. The second stage of work is characterized by crack formation on the borderline between the frame and the cladding. In the third stage of work a diagonal crack develops in the cladding. The results of these investigations make it possible now to carry out combined calculations for the cladding and the frame. The influence of the cladding is taken into account only in the case when solid cladding occupies not less than 30 per cent of the horizontal section of a building. For increasing the load-bearing capacity of the cladding it is desirable to make it by the vibration method.

In the case when the frame is not of complex type it is made of precast reinforced elements which are connected during the erection. Some designs of these joints are shown in Fig. 7. As was noted earlier, such buildings are often designed with curtain wall panels which take comparatively small part in the work of the frame wall in its plane. Tests on recording vibrations of frame walls with curtain panels show that owing to anchors, fixing the panels to the frame, and the possibility of friction periods of free vibrations of such walls are 25-35 per cent lower than in the case when frame walls have no cladding at all. Buildings with curtain walling are characterized by comparatively high flexibility and, hence, by large periods of free vibrations (more than 1 sec.). According to the norms now in force in the USSR siesmic loads for which such buildings are calculated are 2-4 times lower than those for the buildings with the rigid structural scheme.

For single-storey buildings frame structures with self-carrying walls are sometimes used. The height of self-carrying walls is limited for the buildings with the design seismicity of 7,8 and 9 degrees by the dimensions 18, 16 and 9 meters respectively. In the direction normal to the plane of walls they are fixed to the frame by flexible ties; in their own plane they are independent of the frame.

6. Buildings with load-bearing brick and stone walls are erected in regions where these wall materials are locally produced. Such structures are mainly used in regions with the seismicity of 7-8 degrees, the buildings being up to 5 storeys high. For such buildings a number of structural limitations are introduced concerning the dimensions of interfenestration, openings, dimensions and weight of architectural details extending beyond the plane of the wall, etc.

All these limitations as well as the allowable field of using such structures depend upon the category of masonry employed for walls. The category of masonry depends, in its turn, upon its monolithic properties and volume weight. Bonding in the masonry should be for the masonry of the 1st, 2nd, 3rd and 4th categories not less than 1.8, 1.2, 0.6 and 0.3 kg/sq cm respectively. For buildings with the design seismicity of 7 degrees the masonry of all the 4 categories is allowed, while for buildings with the design seismicity of 8 and 9 degrees the norms allow for the use of only the first 3 and the first 2 categories of masonry respectively.

For buildings with stone walls the norms specify the provision of reinforced concrete, reinforced brick and stone antiseismic belts which for the design seismicity of 8 and 9 degrees are located at the level of all the floors. Antiseismic belts are placed using continuous reinforcement along all the longitudinal and transverse walls. The quantity of reinforcement in the belt cross-section should not be less than 4 Ø 10 mm for the design seismicity of 7 and 8 degrees and 4 Ø 12 mm for the design seismicity of 9. For increasing the resistance of joints between slabs of the precast floor to rupture and shear slabs with grooves or corrugated sides are used. Floor slabs are connected by employing special anchor rods and the joints are concreted or grouted. The experiments have shown that the belts play an important role for ensuring the rigidity of the floor in the horizontal plane. They increase the rigidity of floors in their plane 15-20 times.

In regions with the design seismicity of 8 and 9 degrees the masonry is strengthened by vertical reinforcement which is placed either in plaster layers or in special grooves at the ends of sections. Details of belts, fixing of floors and vertical reinforcement are shown in Fig. 8.

Stone buildings are calculated for the action of horizontal seismic forces and vertical loads. The calculation provides for the checking of strength under eccentrical compression and shear as well as strength for principal tensile stresses. The calculation is aimed at restricting crack formation in structures dangerous for their safety; at the same time the norms allow for the possibility of cracks.

7. Large block buildings (buildings whose walls are assembled of separate interfenestration elements, lintels, cill and fascia elements) are comparatively seldom used in earthquake resistant construction since by technical and economic data they are less advantageous than large panel buildings. Designs of large block buildings are shown in Fig. 9. Blocks are made of concrete, brick or stone.

The experience gained during the earthquake in Kamchatka in 1959 proved the safety of such structures for the seismicity of 7 and 8 degrees. While some brick buildings were rather considerably damaged, large block buildings remained absolutely safe.

8. At present buildings composed of three-dimensional elements are being erected for experimental purposes. These elements are produced at a factory in the form of a reinforced concrete box. Each box accommodates one or several rooms. Complete finishing of rooms is provided at the factory. Site operations include only the erection of boxes and the connection of all the services (Fig. 10). At present investigations are being carried out as to earthquake resistance of buildings made of three-dimensional elements. The available experience shows that there might be a wide scope for using this new type of building.

9. Apart from the investigations mentioned above great attention is being paid in this country to studying the problems of strength and deformations of materials under pulsating and impact loads which by their effect are apparently closer to the effects observed during earth quakes than static loads. It has been found out recently that such investigations are to be carried out on samples subjected to preliminary compression, this simulating the conditions of the work of the material under operating loads. It has also been found out that such a load owing to the creepage of materials changes their rigidity and strength and, hence, their earthquake resistance.

10. In this paper it was possible only to broadly deal with problems of designing, construction and investigations carried out in this country in the field of earthquake resistance of buildings. Specialists will naturally be interested in details some of which may be studied using rather extensive publications. These are issued in the form of monographs or articles in special collections or technical periodicals. Special books on the problems of calculating all the abovementioned types of buildings for seismic loads with numerical calculation examples were published in the USSR.

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Table 1.

number of storeys	period (sec.) in the direction: transverse	longitudinal	Category of rigidity
3	0.18	0.18	rigid
4	0.3	0.23	
5	0.32	-	
6	0.38	-	of average rigidity
8	0.43	0.43	

Table 2.

The type of building	Maximum dimensions (m)		Building Height (m)		
	Design seismicity				
	7 and 8	9	7	8	9
With reinforced concrete or steel frames and large-panel without frames	As for non-seismic regions				
With reinforced brick masonry walls and walls of complex type	As for non-seismic regions	the same, but ≤ 80	the same	16	12
With load-bearing stone walls with masonry:					
1 category	the same	the same, but ≤ 60	the same	16	12
2 "	"	the same, but ≤ 40	"	12	9
3 "	"	"	"	8	-
4 "	"	"	"	-	-
Wood	non-limited				16

Table 3.

Wall designs	Weight in various designs kg	Average weight kg	Relative average weight
Of solid brick	2300-2400	2400	1
Of concrete and reinforced concrete panels	1000-1500	1250	0.52
Of vibro-brick panels	1500-1700	1600	0.67

Table 4.

Type of material and masonry	Ultimate strength kg/cm^2	
	in shearing	in tension
Heavy concrete of 200 grade	35	16
Cellular concrete of 100 grade	17	9
Cellular concrete of 50 grade	8	5
Vibro-brick masonry made with cement mortar	8	5
Non-vibrobrick masonry	3.5	1.8

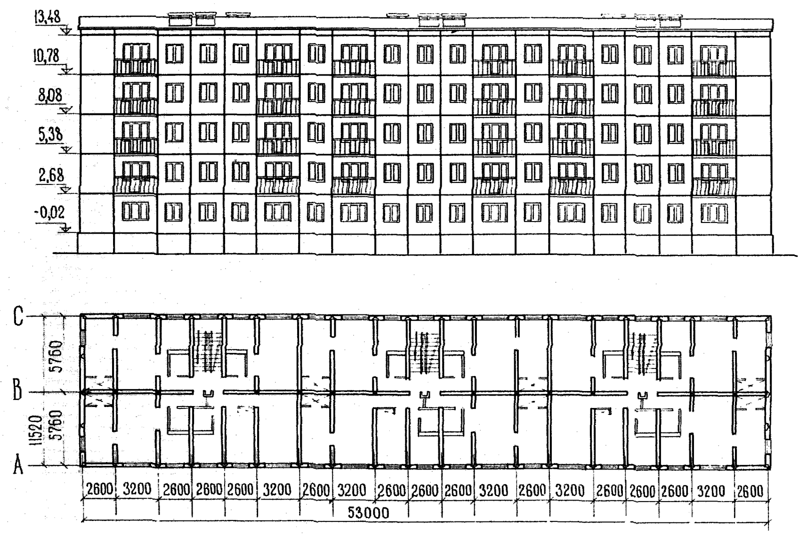

Fig.1 Façade and floor plan of the building made of reinforced concrete panels.

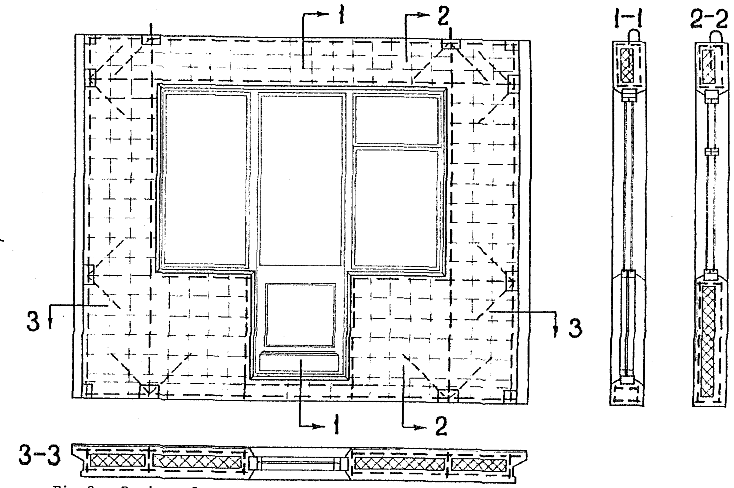

Fig.2,a Design of a reinforced concrete panel for the external wall.

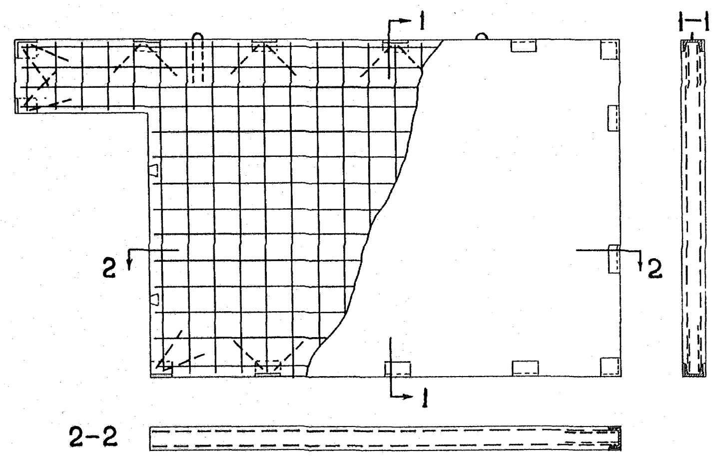

Fig.2,b Design of a reinforced concrete panel for the internal wall(*mesh reinforcing*)

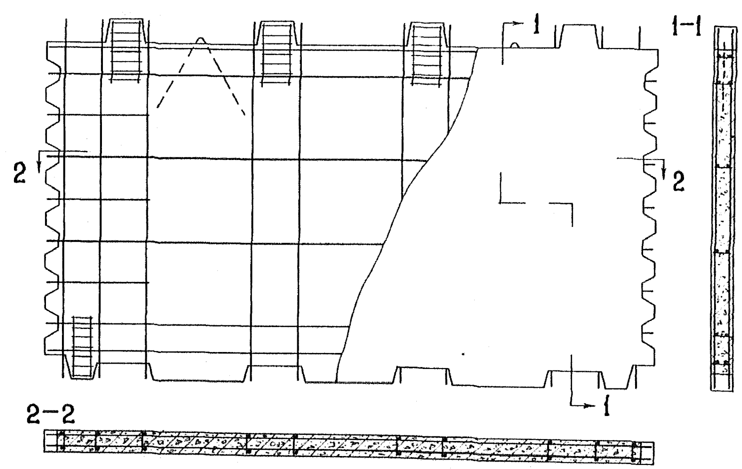

Fig.2,c Design of a reinforced concrete panel (cage reinforcing).

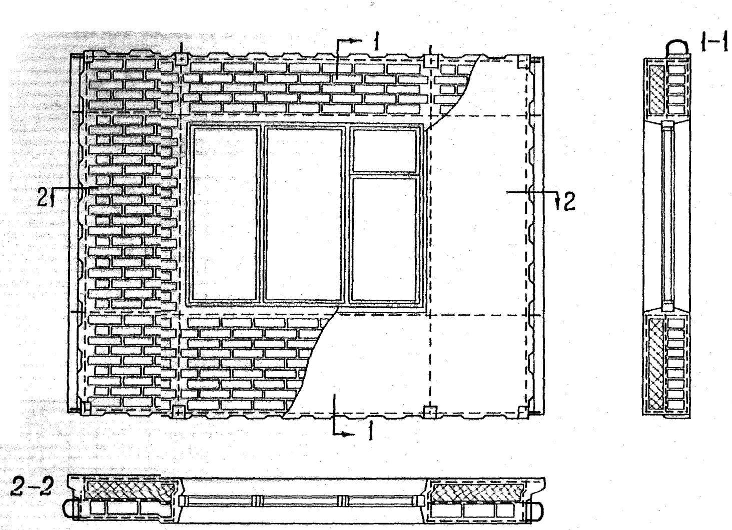

Fig.3,a Design of a vibrobrick panel for the external wall.

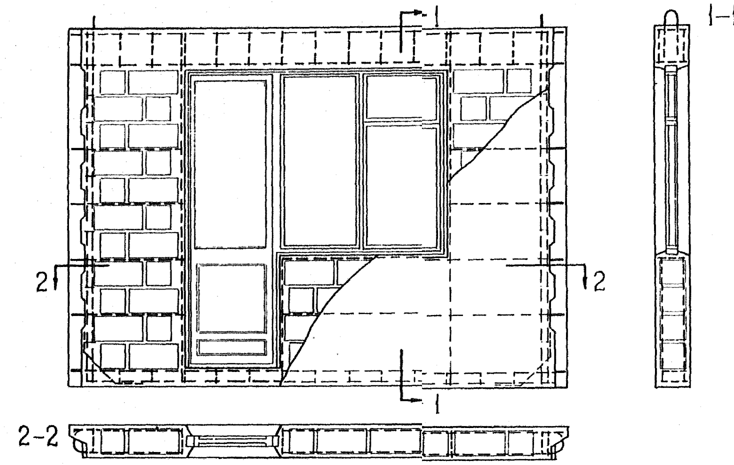

Fig.3,b Design of a vibrostone panel for the external wall.

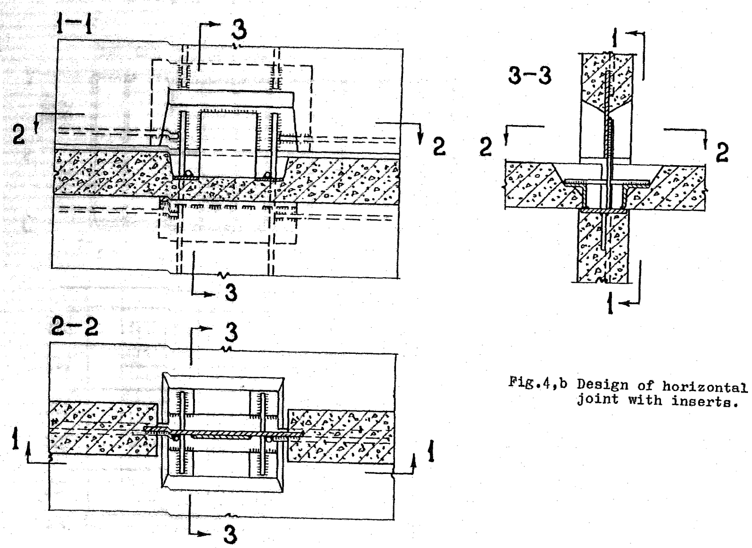

Fig.4,b Design of horizontal joint with inserts.

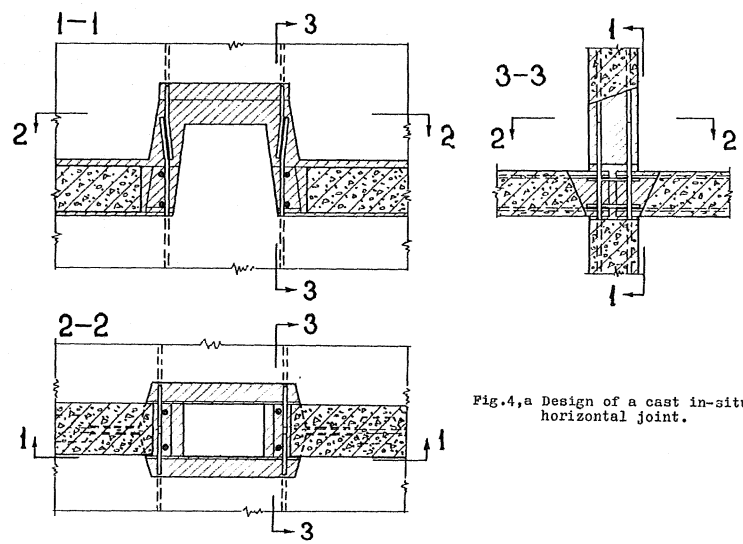

Fig.4,a Design of a cast in-situ horizontal joint.

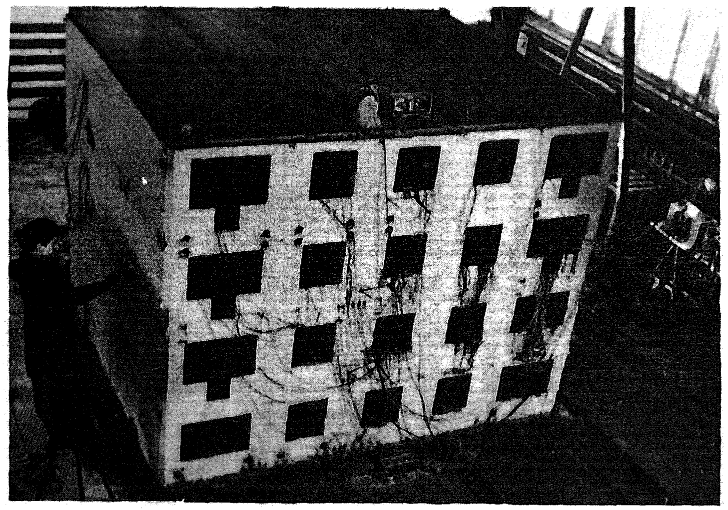

Fig.5 Model of the large panel building on the seismic platform.

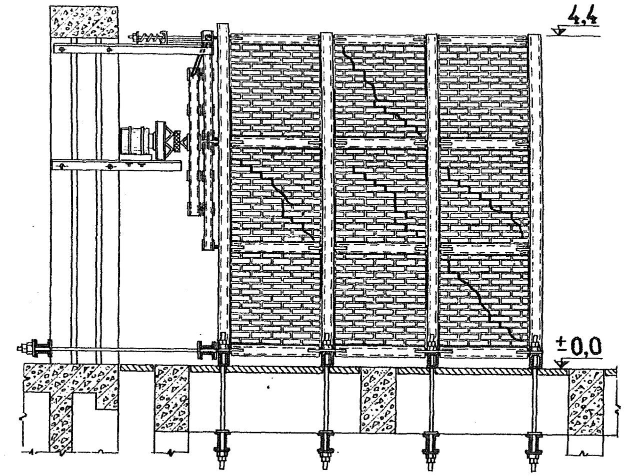

Fig.6 Scheme of testing brick cladding of 3-storey steel frame.

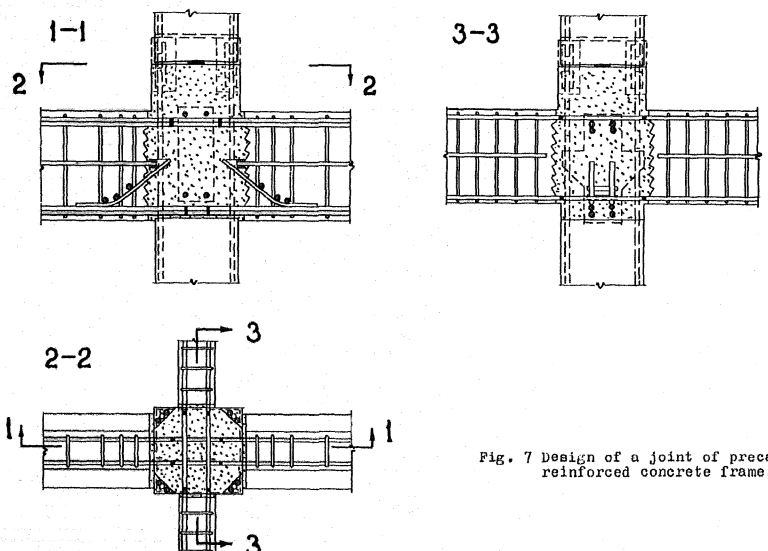

Fig. 7 Design of a joint of precast reinforced concrete frame.

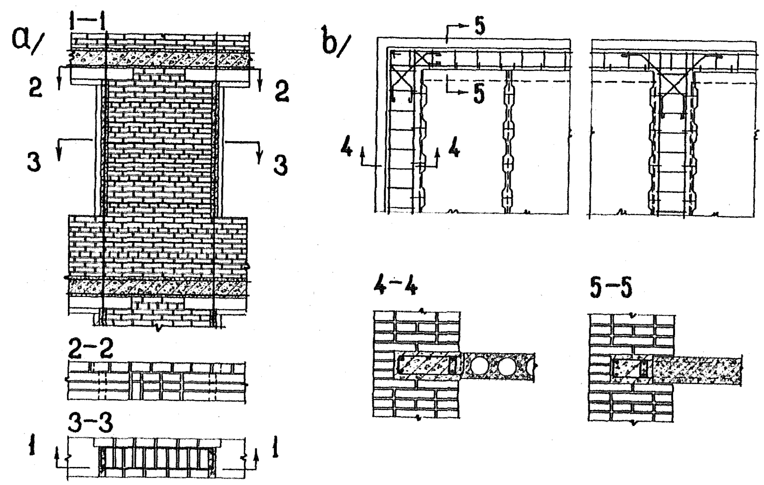

Fig.8 Details of wall structures of brick buildings.

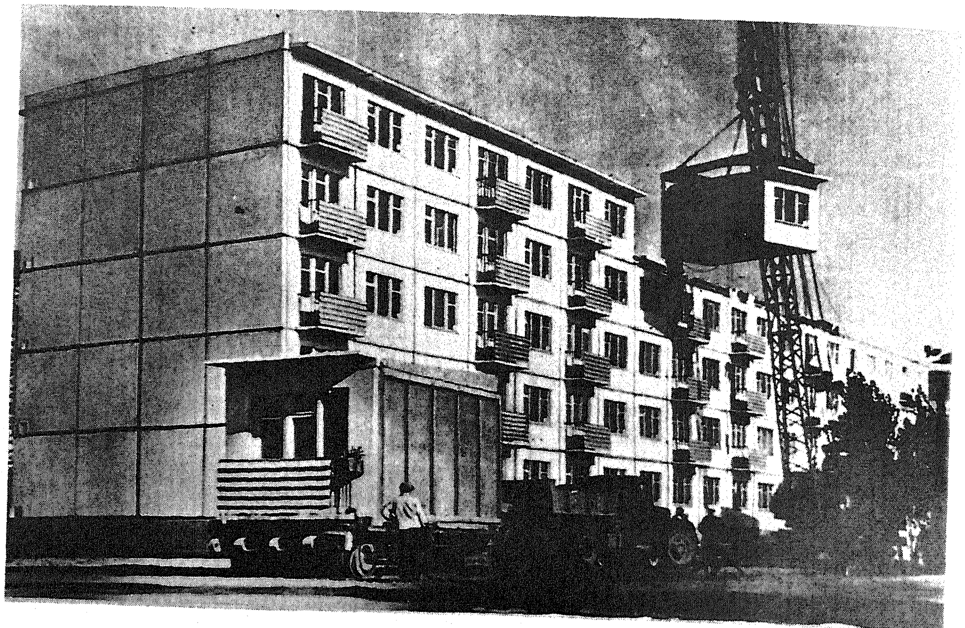

Fig.10 Erection of the building made of three-dimensional elements.

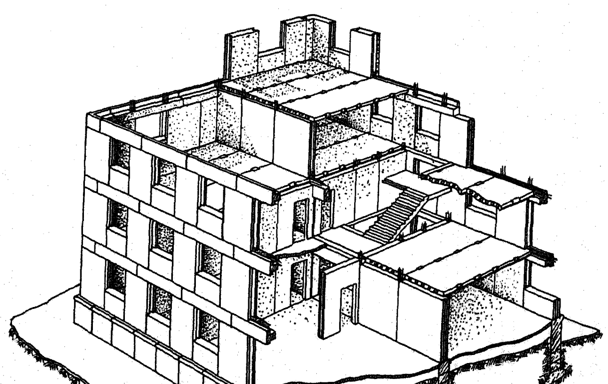

Fig.9 Scheme of a large block building.