GUARANTEEING ANTISEISMICITY OF BUILDINGS ON THE BASIS OF INVESTIGATIONS CARRIED OUT IN THE USSR

By

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Systematic investigations on problems of antiseismicity of buildings in the USSR date from the second quarter of the 20th century, i.e. they were begun soon after Gori and Leninakan earthquakes. At the same time a progressive dynamic theory of antiseismicity was suggested, this theory was developed later on and was assumed as a basis for designing aseismic structures. Simultaneously aseismic constructions for buildings and other structures were developed. The present paper gives an account of the present state of investigations which are carried out in the Soviet Union on aseismic constructions in buildings.

In the first phase of a destructive earthquake sharp impact causes damage of rigid parts of the building. In the second phase long seismic waves shatter the building and complete the destruction which begins in the first phase. This is an approximate way of the behaviour of a building during an earthquake.

The structure may be considered as a bar whose lower end is clamped in the ground and upper end is free only in those cases when either its transverse horizontal dimensions are small enough in comparison with the height of the structure or when additional constructions guarantee unalterability of horizontal sections. The first case includes structures of tower-type, i.e. towers, chimneys, lighthouses, siloes, etc.; the second case includes high non-skeleton buildings with thickly set walls and partitions closely connected between themselves and with floors.

However, the most part of the buildings erected in seismic regions should be regarded as boxes which deform not only in vertical planes but in horizontal planes as well. The walls perpendicular to the direction of the impulse behave as slabs connected along the contour with the walls and floors parallel to the direction of seismic forces. The walls parallel to the direction of the impulse are chiefly subjected to bending or shear depending on the correlation of their face dimensions-- vertical and horizontal. These walls get horizontal loads from the walls perpendicular to them and from floors.

For a long time the only type of capital buildings in the seismic regions of the USSR was the type with stone walls (chiefly with brick solid walls) and wooden floors. Later on wood in floors was gradually substituted by reinforced concrete and subsequently, with the development of built-up concrete and reinforced concrete construction, the erection of walls of large concrete blocks and even of reinforced concrete panels whose dimensions were designed for a room was put into practice. Lately there appeared a new method of assembling buildings of ready-made three-dimensional cases each case presenting a room. At the present time buildings with solid stone or brick walls still predominate in seismic regions but side by side with

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*Institute of Building of the Georgian Academy of Science (USSR) them buildings of large blocks and large panels and buildings of ready-made rooms are being erected on ever growing scale. Therefore the present paper considers the problems of guaranteeing antiseismicity for all these types of buildings.

1. Building with Solid Stone Walls

It is well-known that with the increase of flexibility of the whole construction the influence of seismic forces decreases. At the same time in order to avoid the breach of connection between parts of constructions it is necessary to get rigid interconnections between them. Therefore the main principle of reinforcement against an earthquake is reduced to bringing separate parts into an unalterable connection by means of ties, at the same time providing as large as possible rigidity of the structure on the whole. Rigid interconnections by themselves experience increased forces, which are conditionally supposed to be fivefold comparing to exiting effects, but it eliminates the possibility of the breach of the building integrity. Guaranteeing the strength of ties causes quite moderate rise in cost of the building as their total volume is small. The most vulnerable parts of the building are projecting elements whose masses are rather small in comparison with the mass of the whole building, i.e. projections of gable walls, chimneys, pediments and parapets. Therefore building such parts should be avoided and in cases when it is inevitable they should be reinforced.

The walls perpendicular to the direction of seismic impulse behave as slabs supported along the contours upon the walls perpendicular to them and upon the floors. If the former walls are weakened by window or door apertures they should be designed as vertical beams (piers) or horizontal beams (seals). Calculations show that if the dimensions are usual sufficient resistivity of walls to such bending is gauranteed in case they are well connected with walls of another direction at places of abutting or intersection. But non-bearing walls are especially endangered as during an earthquake they may be torn away from longitudinal walls. As a proved measure of interconnecting walls we use reinforced concrete belts (girders) extending continuously along all walls at definite levels. The higher is the seismicity of the region the thicker such belts are set. The masonry of walls should be well connected with belts. If floors are securely connected by means of special members with the walls which support beams and with the walls parallel to the latter, the necessary in reinforced concrete belts falls away. It is especially simply achieved at reinforced concrete floors, concreting being made on site (monolithick floors).

The walls parallel to the direction of seismic forces behave as beams clamped into the ground with their lower end and subjected to the action of horizontal seismic forces corresponding to the masses of the walls designed and to the masses of those parts of floors and walls of another direction which load the wall being considered. Under the action of these forces the wall works to bending and shear and depending on the relation of the wall height to its length either bending or shear prevails. In seismic regions we chiefly deal with buildings with a limited number of storeys, i.e. with buildings in which the walls parallel to seismic forces more often work to shear; this is testified by sloping cracks directed at an angle close to 45° (Fig. 1).

If the wall parallel to the direction of seismic impulse is weakened by apertures, horizontal forces are distributed among piers proportionally to their rigidities. Therefore broad piers are especially much loaded. On the whole they are damaged at the expense of large values of seismic forces acting upon them and at the expense of higher dynamical coefficients which as it is well known rise with the increase of the rigidity of a structure. It should be noted that broad piers are chiefly damaged by shearing forces (sloping cracks) and narrow piers are damaged more often by bending moments with horizontal cracks along the pier edges (Fig. 2).

It is most expendient to design walls with piers of equal width. In such cases seismic forces are distributed among them equally. The character of pier damage essentially depends on the location of the earthquake epicentre with respect to the building. If the epicentre is located nearby, considerable values of vertical component seismic forces promote the development of sloping cracks on broad piers. If the epicentre is far, the influence of bending prevails and on narrow piers horizontal cracks develop for the most part.

The corners of buildings appear to be in a hard state (Fig. 3).

The rigidity of edge piers, the tendency of adjoining walls to tear off from each other and asynchronomity of oscillations in meeting walls are of importance here. It confirms the necessity of the arrangement of reinforced concrete belts or other ways of wall interconnecting.

It is clear from all stated above that effective measures for guaranteeing the safety of buildings with solid stone walls are as follows:

1) the arrangement of reinforced concrete belts or connecting floors with the walls of both directions;

2) the even distribution of apertures along the length of the wall.

3) the establishment of limit distances between walls and limit height of the story.

2. Buildings with Skeleton Walls

Experience shows that damage of reinforced concrete frames is often characterized by forming plastic hinges in the joints of the frame. Therefore joints should be strengthened by rubbles and reinforced accordingly. Besides, insufficient cross-section or inadequate reinforcement cause the damage of the lower ends of the columns, the concrete reinforcement becoming bared and buckled. Then, in order to avoid falling out the filling it is necessary to tie it firmly with elements of the frame. The frame should be sufficiently rigid, otherwise brittle masonry of the filling which is unable to follow deformations of flexible frame elements will be subjected to considerable forces in its plane and gradually will fail, especially if it is weakened by apertures.

If the filling is separated from the frame, if it is located on the outside and is supported by the foundation beams, the safety of such "self-bearing" walls depends on the character of connection between them and the columns of the frame. In such cases a through joint between the walls and the frame is necessary in order to avoid mutual impacts; the connections between them should be flexible.

3. Buildings of Large Blocks

Earthquake-proofness of walls erected of large blocks is provided by constructive solutions analogous to constructive solutions for stone (brick) walls. It is vitally important to secure reliable bond between blocks and mortar. It is achieved by placing blocks under pouring which eliminates the possibility of damaging the mortar at placing blocks to the previously laid mortar. Blocks are mounted dry on wooden wedges making clearance under blocks which corresponds to the thickness of the joint. After the adjustment of a row is completed horizontal and vertical joints are shut from the outside and pouring with mortar under same pressure is effected. As to the floors, for achieving monolithic system they are connected with each other on each side by keys (Fig. 4).

Reinforcement of two adjoining blocks in keys is connected with welded-on metal plates or clips. Rods of cross-section reinforcement are placed close to the keys. Such interconnections bring all floor slabs into monolithic bond and, on the one hand, they guarantee earthquake-proofness of the system and, on the other hand, they guarantee vertical rigidity of floor since all of it works as a single three-dimensional system. It should be noted that, as experience showed, in case of placing floor slabs without making them monolithic longitudinal cracks appear in the ciling plaster along the lines of slab boundaries.

4. Buildings of Large Panels

Buildings of large panels are built with or without a frame. Among frame buildings of large panels the buildings with full frame of columns and girders rigidly connected with each other in the joints are most earthquake-proof. At the same time in order to eliminate the possibility of brittle destruction at rigid connections it is necessary to apply dispersed reinforcement which includes a large number of thin rods. This makes possible the development of plastic flow and the increase of the structure resistivity to short-timed action.

Among the buildings without frame the buildings with transverse bearing walls are preferable for seismic regions. They have some advantages over frame buildings.

For increasing their earthquake-proofness the following supplementary measures should be adopted:

1) the shape of buildings should be rectangular, in the plan, in case of complex shape they should be devided by antiseismic joints into rectangular sections;

2) the walls should be continuous at full length and width of the building;

3) the walls should have smooth surface without projections and be

surmounted only by a small eave and a low parapet;

4) the length and width of the panel should be as large as possible at the expense of its thickness as that will reduce the number of assembly joints presenting the most vulnerable places;

5) a flat roof should be preferred as it results in a rigid membrane securely connecting the walls.

For the last time there spread buildings by the system of engineer Lagoutenko; their bearing transverse walls are formed of thin panels with bulges along the contour; the panels support each other at the ends and consequently work to bending but not to compression. When analysing this scheme from the point of view of its earthquake-proofness we can notice its following advantages:

1) small weight due to the use of thin-walled vertical and horizontal panels;

2) monolithic connection of slabs, serving as the filling of the frame, with bulges along the contour forming the frame after assembly.

3) small loading of the partitions (only their own weight and the weight of one story floor).

The shortcoming of the scheme is the necessity of careful making monolithick joints and small rigidity in longitudinal direction.

The most perfect scheme with respect to earthquake-proofness is the schome with bearing longitudinal and transverse walls and partitions working to compression. In this scheme considerable reduction of free span of the walls is achieved. If the materials are effective and the methods of making vertical panels are progressive (panel-casing method and vibrorolling method) close arrangement of bearing vertical elements of buildings does not cause the increase of the general weight. Such building possesses considerable three dimensional rigidity, as it consists of closed invariable cases, each being made of 4 partition panels and a floor panel. The behaviour of floors improves as within the limits of the room they present slabs supported along the whole contour which increases their rigidity and lightness. High earthquake-proofness of such scheme by itself eliminates the necessity in special aseismic measures.

5. Buildings of Three-Dimensional Elements

The most progressive scheme of built-up reinforced concrete buildings is the scheme of three-dimensional elements presenting ready-made room blocks. This scheme is a good solution for seismic regions as well. Buildings consisting of three-dimensional elements whose width is equal to the width of the building are especially earthquake-proof. Such schemes are particularly tempting due to the fact that for installation of built-up elements it is possible to use gantry-cranes moving along the tracks laid on the outside along the whole length of the buildings. Such portal-cranes are considerably lighter of the usual tower cranes with the same lifting power, especially if the places of suspension of built-up element are fixed close to supports of the crane beam (Fig. 5). High earthquake-proofness of such buildings is caused by the fact that they consist of light and rigid three-dimensional elements which behave as box girders.

However, separate built-up elements should be mutually and securely connected.

6. Interconnections of Elements in Buildings of Large Panels Erected in Seismic Regions

The Institute of Building of the Georgian Academy of Science worked out constructions for interconnecting elements of large panel buildings. When the seismicity is equal to 7 free joint of the wall is fulfilled as it is shown in Fig. 6.

Loops located in the limits of the slot are let out of the panel. The sense of such interconnection consists in the fact that the concrete in slats does not need by itself the strengthening by means of reinforcing. But the bond of fresh concrete and old concrete is a vulnerable place and the reinforcement should strengthen precisely this bond. For filling the slat with concrete there is no need in timbering.

At seismicity equal to 8 and 9 such connection between wall panels is already insufficient. It is necessary to have such design of connection which would strengthen the resistance of the canal filling to rupture. The design presented in Fig. 7 meets the requirements. Here reinforcement outlets outstep the limits of slats to get them overlap each other during assembling. Four vertical rods are inserted into the loop which forms, at this time after this slats are poured with concrete.

While making such panels it is necessary either to leave slits in moulds to let the reinforcement out or to insert loops in bent state and straighten them later, in the ready panel.

The corners of the building require especially large strengthening. Interconnections in corners for seismicity 7, 8 and 9 are shown in Fig. 8 and 9. The same loopes which have just been mentioned are used with the strengthening consisting of vertical rods but on top there are additional fastenings in the form of welded laid parts. Fig. 10 shows the interconnection at the place of the adjoining of internal and external walls, Fig. 11 shows the interconnections at places of the crossing of internal walls. In both cases loopes are arranged at different levels and are somewhat shifted in relation to other loops meeting with them in the plan.

The connection of floors with the external wall is provided by constructions depending on the thickness of the wall. Floor panels not less than 35 cm thick are supported to the depth of 25 cm without fastening to the wall. When the wall width is less the connection is achieved by welding of laid parts, and the projections of wall panels should be strengthened by vertical reinforcement (Fig. 12).

The supporting of floor panels onto the internal walls is carried out directly at the wall thickness of 26 cm which lets the depth of supporting be equal to 12 cm and thickness of joint 2 cm. The connection between wall panels (of the given and the next storey) is carried out with the help of vertical rods (Fig. 13).

In order to achieve this into vertical canals formed between the panels are inserted metal frames (60-80 cm long) consisting of 4 rods. It should be noted that the half-length of the frame is placed into each panel. Previously to the mounting of the frame the canal of the given assembled story is poured with concrete up to the level 30-40 cm lower of the upper edge of wall panels. After this a ready frame is inserted into the canal. The diameter of the frame rods is adopted 10 mm for seismicity 7-8 and 12-14 mm for seismicity 9.

All above mentioned types of interconnections bringing elements of large-panel buildings into invariable mutual connection thus guaranteeing their earthquake-proofness are to a certain extent necessary for non-seismic regions. Therefore the strengthening of large panel buildings of a normal height of an order 5 storeys against the action of seismic forces does not result in considerable increase in costs and complication in their erecting. For buildings more than 5 storeys high it is necessary to work out methods of more essential strengthening. The working out of these methods reflected in Fig. 10 and 11 brings us to the recommendation of buildings with "frame without timbering" in which basic interconnections are carried out according to Fig. 14. The pouring of canals with concrete does not require any timbering and after pouring is completed the frame is formed which is securely connected with panels serving as the filling.

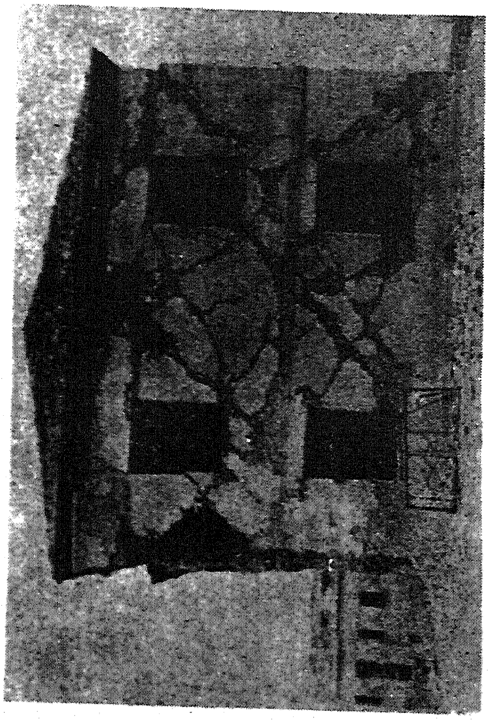


Fig. 1

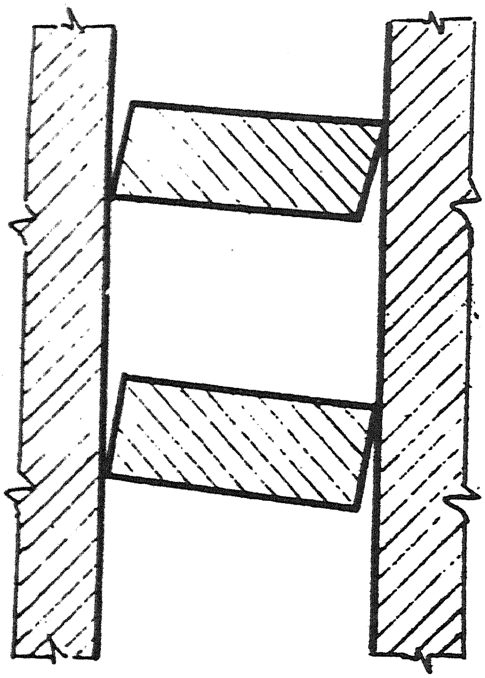


Fig. 2

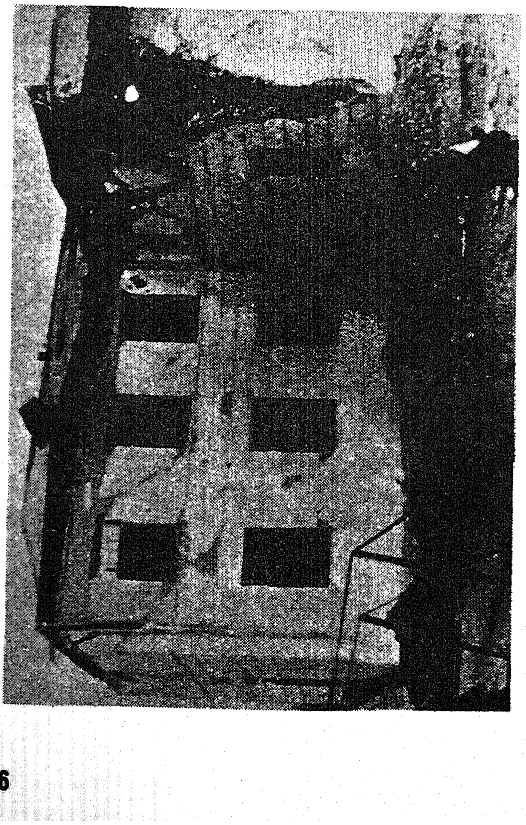


Fig. 3

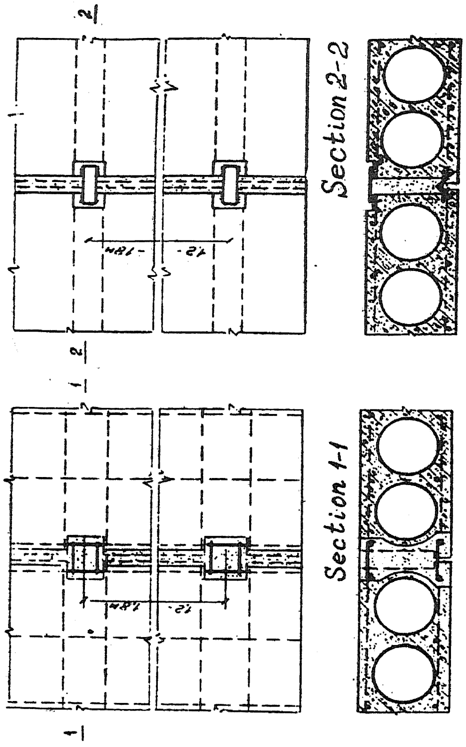


Fig. 4

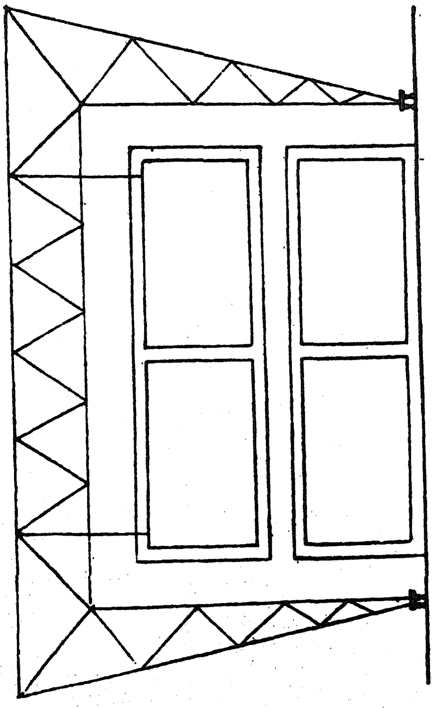


Fig. 5

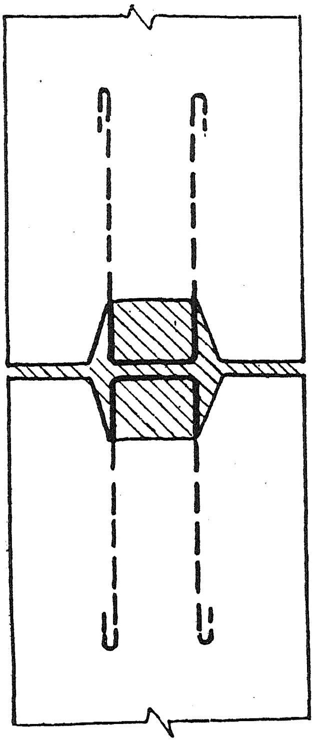


Fig. 6

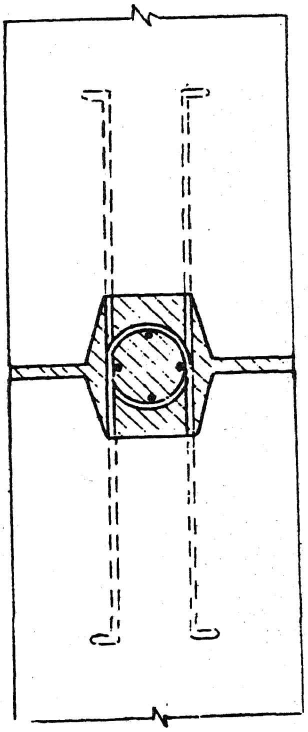


Fig. 7

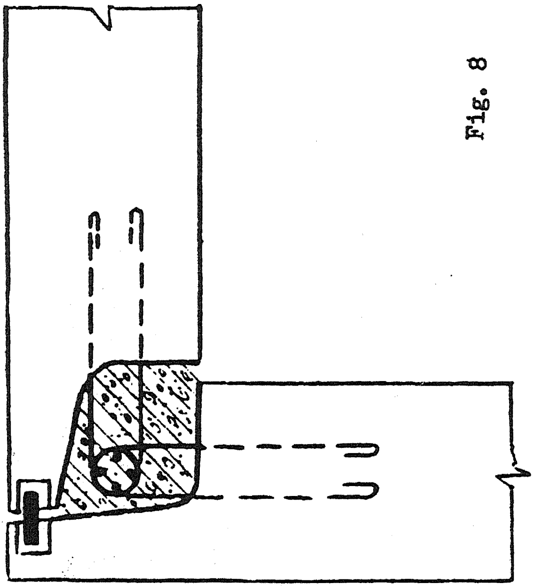


Fig. 8

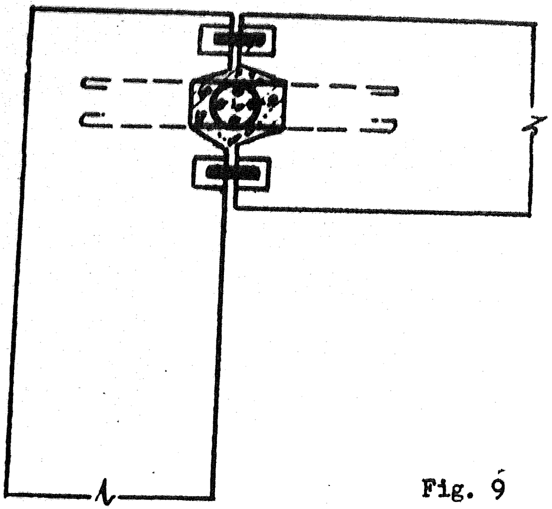


Fig. 9

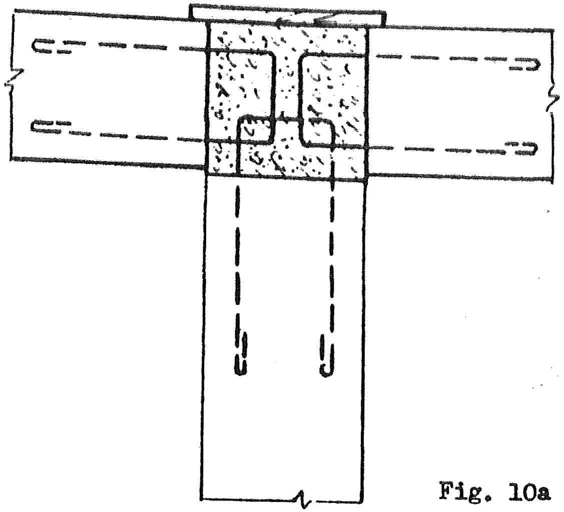


Fig. 10a

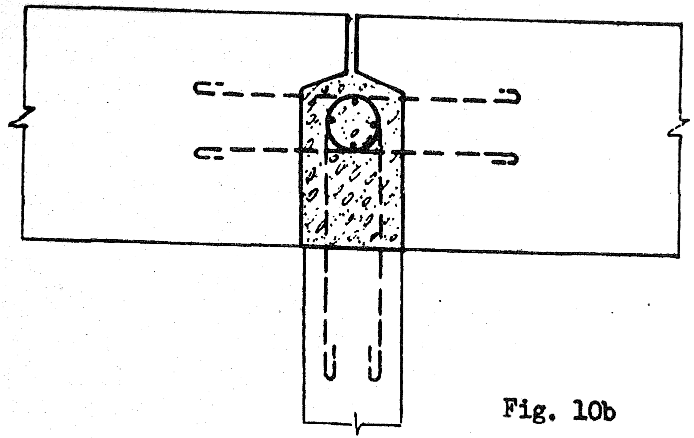


Fig. 10b

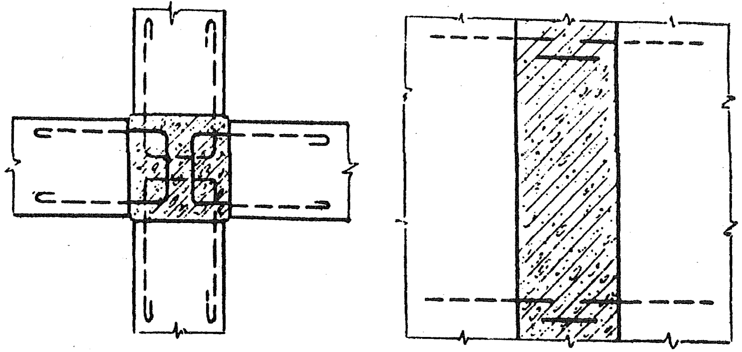
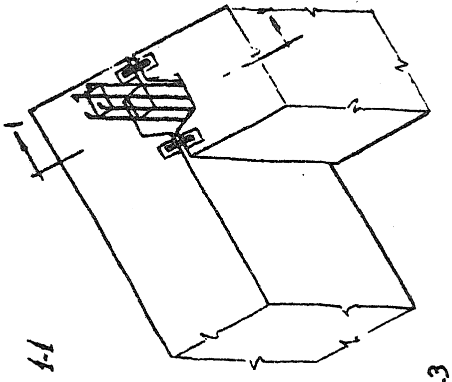
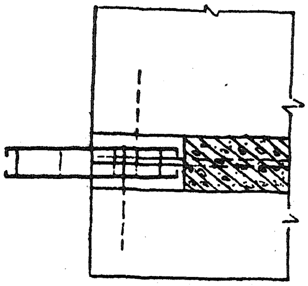


Fig. 11





Section 1-1

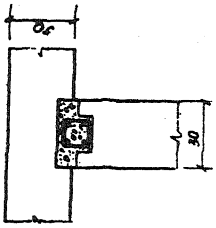
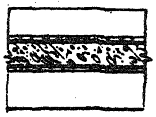


Fig. 13



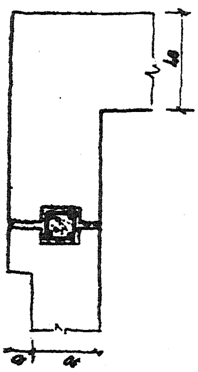
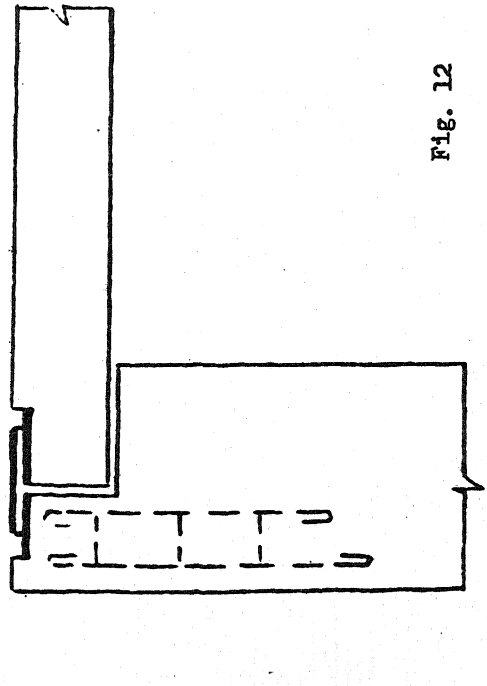


Fig. 14



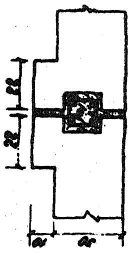
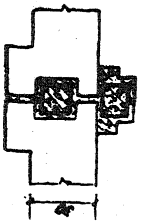


Fig. 12



K. S. Zavriev

DISCUSSION

K. Kubo, University of Tokyo, Japan:

I much appreciated your paper presented. Is such an interconnection device as you mentioned widely in use, and is there any example of seismic damage to that practice?

K. S. Zavriev:

The device in question is now standard in the construction of precast buildings. Tests, both static and dynamic, have been performed on full-size specimens and have proved to be satisfactory. As to date, none of the buildings so constructed have yet experienced on earthquake.