# THEORETICAL AND EXPERIMENTAL INVESTIGATIONS OF SEISMIC-RESISTANT BOX-UNIT STRUCTURES (5-95)

by

T.Kh. Bukharbaev[I]

## SYNOPSIS

This paper reports on some new results of theoretical and experimental investigations of seismoresistance of thin-walled spatial structures - box-units. A technique is proposed for determination of stress-strained condition of box-units with consideration of the spatial mode of their behaviour. The technique shows good agreement with experimental data. Disagreement is observed between calculation results obtained from the spatial design method and those from the traditional plane design method. The full-scale tests of a three-storey box-unit structure under vertical and lateral, static and dynamic loads are described.

The analysis and experimental data have helped to reveal and analyse both the qualitative and quantitative pictures of distribution of stress and strain in walls of box-units under lateral and vertical loads.

The conclusion has been drawn that it would be sound practice to use box-unit systems in earthquake engineering.

## TECHNIQUE OF ANALYSIS

A technique based on the use of the finite-strip method is proposed for determination of stress-strained condition of box-units, taking into consideration the three-dimensional mode of their deformation/ 1,2,3/. The calculation technique allows to determine the stress-strained condition of thin-walled box-unit prismatic structures, taking account of real structural features - apertures, haunches, ribs, adjoining walls, etc. As an illustration of the technique potentialities for plane and spatial schemes of design, fig.1 shows a form of strain and diagrams of normal stress of the box-unit with 6 cm-thick walls of 300 $kg/cm^2$ strength heavy concrete with $3.15 \times 10^5$ $kg/cm^2$ modulus of elasticity and 0.18 Poisson's ratio.

## SPATIAL RIGIDITY ANALYSIS

It is ascertained that taking account of the spatial behaviour results in a considerable increase of thin-walled prismatic element rigidity. The increase equals 20 to 40% for longitudinally-directed box-units and reaches 80% for lateral ones, depending upon their construction details and arrangement of window and door openings in the wall planes.

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[I] Chairman of Gosstroy of the Kazakh SSR, Alma-Ata, USSR.

Determination of true location of rigidity centres at the ceiling slab levels is of great importance for thin-walled box-units used in seismic zones. An examination has shown a great difference in the rigidity centre locations in box-units designed by the spatial and plane schemes of design. In the plane design the box-unit rigidity centre is always within the box-unit plan contour. In the spatial design the box-unit rigidity centre may be outside the plan contour. The latter is the most characteristic of the box-unit with a large opening on one side, as fig. 2 shows. It is similar to the behaviour of the thin-walled channel with the rigidity centre outside its cross-section. Distances from centres of mass to rigidity centres of box-units designed by the spatial scheme are greater, as a rule, than those in the plane one, and may differ by up to 50%. This is of rather great practical importance, since the arrangement of the planes of external force action outside the rigidity centres results in considerable additional strain and stress in the supporting structures of box-units, which should be taken into consideration during determination of their supporting capacity.

It is obvious that integration of separate box-units in a unified building may, to a certain extent, prevent appearance of additional stress or reduce it. In this connection, the use of box-unit systems of poorly-jointed or non-jointed box-unit pillars is not expedient in earthquake engineering.

## STRESSED STATE ANALYSIS

Stressed states of walls of box-units under vertical and lateral loads also differ considerably when compared in plane and spatial schemes of design.

Effectiveness of taking account of the spatial behaviour in determination of the stressed state of box-units has been evaluated by the comparison of wall normal- and tangential-stress diagrams obtained from the plane and spatial discrete schemes of design. Fig. 3 shows diagrams of box-unit wall stressed state under lateral loads for plane and spatial designs.

Being influenced by the adjoining walls, normal stresses most appreciably change in narrow piers of the perpendicular walls where they are reduced 2 or 2.5 times, conserving their common distribution character, however. Some qualitative difference is observed in plane and spatial design diagrams of normal stress in spandrels over the window and door openings (fig.3). With taking account of the spatial deformation of box-units, the diagram approximates to the one-sign triangular diagram, and becomes triangular when the floor can be considered absolutely stiff in its plane. Thus, a qualitative change takes place in spandrel stressed state with replacement of reverse mode bending by eccentric compression or tension, the maximum values of normal stress in spandrels being 10-30% lower for the spatial design.

The maximum tangential stresses in the middle of the walls of box-units of the spatial design increase insignificantly as compared with the plane design. At the same time the wall edge tangential stresses increase appreciably due to the effect of the tangential stresses in perpendicularly-directed walls.

## EXPERIMENTAL DATA

To examine the box-unit structure for earthquake resistance, the authors performed a full-scale test of a three-storey building consisting of eighteen thin-walled reinforced-concrete box-units under vertical and lateral, static and dynamic loads /4, 5/. A specific stand was used for this purpose, the maximum lateral load was 220 tons with the total weight of the structure - 340 tons.

In the dynamic test vibration period changed from 0.18 to 0.42 s with an increase in the load, the maximum lateral displacement of the building top was 17.5 mm, vibration damping in the range of 7 to 10% of the critical one, the maximum accelerations of lateral vibrations reached 0.07 g at the base level and 0.56 g at the top level.

The full-scale tests of the box-unit structures have shown that under vertical and lateral loads the supporting structure material displays elasto-plastic behaviour, with reversibility of deformations, opening and closing of cracks, and with the yield ratio of the order of 1.5-2.0.

In the test under greater loads equal to 65% of the building own weight, stress in walls has not reached the design compressive strength of concrete ( 300 $kg/cm^2$).

The box-units of 40 mm thick walls have withstood the lateral loads 2.5-times exceeding the design ones for intensity 9 by the USSR code, without failure and local destruction. This, to a great extent, is accounted for by the spatial effect of the walls and ceiling interaction, which results in an appreciable increase of their carrying capacity.

Comparison of the above described analysis data with the experimental ones has shown their good agreement in the elastic range.

## CONCLUSION

The results of the above described research show that taking account of spatial ability of box-unit structures allows to more authentically reflect peculiarities of their stress-strained condition under vertical and lateral loads, reveal their carrying capacity reserves, and elucidate cases of wall angles and spandrels failure observed during earthquakes.

On the basis of the experimental and theoretical research,the authors have come to the conclusion that thin-walled reinforced-concrete box-unit elements feature high spatial rigidity and carrying capacity. It seems possible to recommend them for use in earthquake engineering on condition of reasonable analysis and design.

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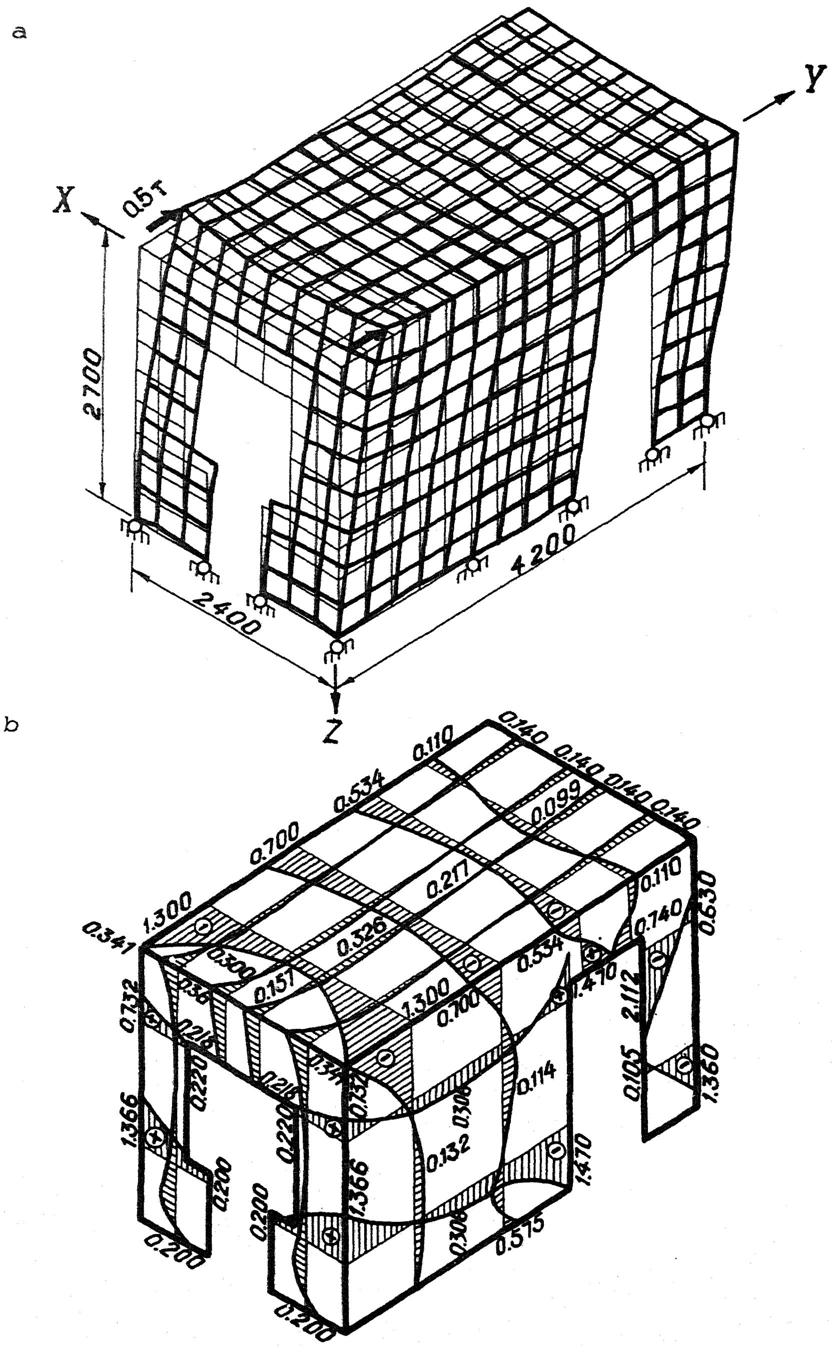


Fig.1. Diagrams of Spatial Strained (a) and Stressed (b) States of Box-Unit Under Lateral Forces

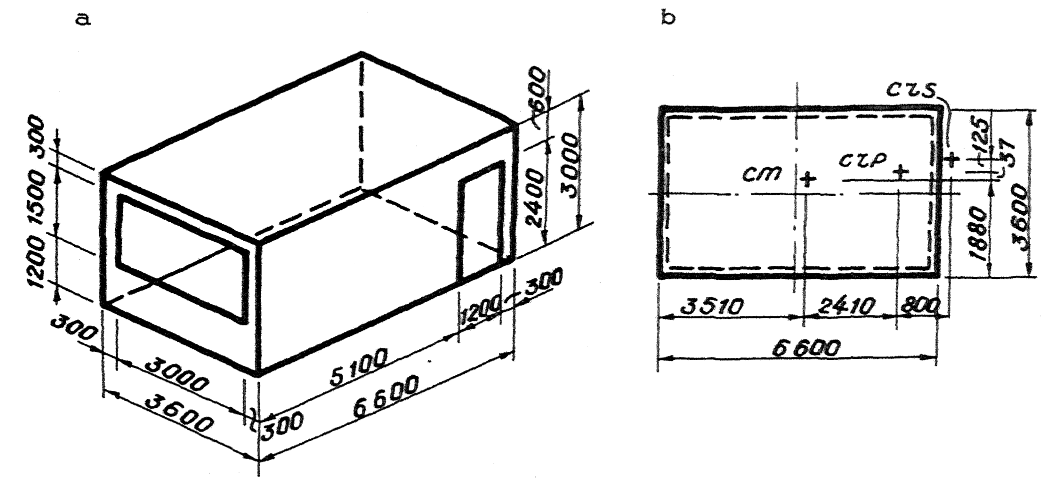


Fig.2. Rigidity Centre Location at the Box-Unit Floor Level

a – design scheme of box unit;

b – rigidity centre location in spatial (crs) and plane (crp) schemes of design;
cm – centre of mass

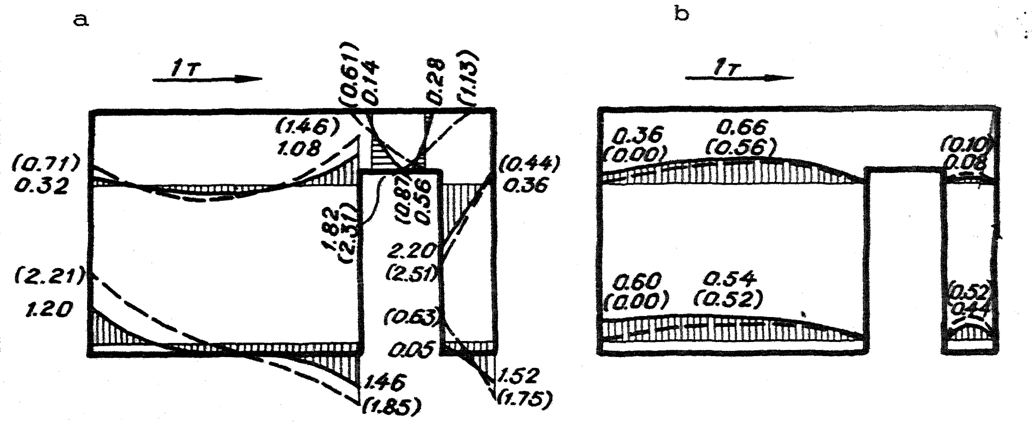


Fig.3. Diagrams of Normal (a) and Tangential (b) Stress in Walls of Box-Units Under Lateral Load, with the Use of Spatial and Plane Schemes of Design

(solid line – stress in spatial scheme of design, dash line – stress in plane scheme of design)