ON ONE METHOD OF INCREASING THE SEISMIC STABILITY OF BRICK BUILDINGS

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Summary

Authors of this report worked out the method of strengthening the brick buildings, based on the experiment of earthquakes and on the Naito's principles about distribution of seismic loading among the constructions in proportion to their hardness.

This method is the combination of strengthening the buildings by vertical reinforced concrete elements and by horizontal reinforcement. The authors of the report worked out also the method of strengthening by vertical reinforcement the prefabricated high buildings. In both cases it is supposed that laying holds enough satisfactory quality.

The Text of Paper

The latest earthquakes in the USSR and abroad (Ashkhabad, Tashkent, Agadir, Skopje) reaffirmed that brick masonry, owing to poor quality of materials and technique of setting, does not offer sufficient resistance to the seismic effect and that it is precisely this circumstance that causes mass collapses of buildings during earthquakes. Taking into account that in the next few years the share of brick among other masonry materials will still be fairly considerable, it is necessary to increase the quality of brick masonry and work out some techniques for strengthening brick buildings. These techniques should be based on data of the behaviour of brick buildings during an earthquake and on the results of their design analysis.

It is known that collapse, characterizing the maximum state of a building as to seismic stability, may as a rule,

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occur anly as a result of wall toppling under the influence of forces perpendicular to their planes. Toppling of walls is preceded by disturbance of connections between them at the outer corners and at the contiguities of the inner and outer walls. Experience with earthquakes shows that it is precisely conjugations of the puter walls and, primirily, the corners, that constitute the most vulnerable parts of buildings. It is precisely in these parts that tearing cracks appear which, during a prolonged seismic effect, result in the toppling over of walls, as a rule of non-bearing ones. It follows from this that in working out techniques for increasing the seismic stability of brick buildings the attention should principally be paid to the strengthening of the conjugations of the outer walls, as well as of the connections of the outer non-bearing walls with corners and contiguities.

The sections of brick masonry requiring such strengthening against the effect of seismic forces along wall planes are: piers into which slanting cracks or cross-over slanting cracks appear; over-opening sections where along with slanting cracks vertical cracks appear, and sections for fixing lintels.

According to unified strengthening of brick buildings with estimated seismicity of strength 9, designed in the USSR by the Central Research Institute of Building Constructions jointly with the Institute of Structural Mechanics and Seismic Stability of the Georgian SSR Academy of sciences, the following wall parts are to be strengthened: piers - by providing reinforced concrete bars or longitudinal / vertical reinforcement along the side edges of the piers; above-opening masonry and sections for fixing lintels-by providing monolith reinforced concrete lintels, matched with a band, and continuous reinforced joints at the level of window sills. These joints, together with lintels, form a double reinforcing of the above-opening of the strip of the wall, thereby increasing its stiffness and strength and thus relieving the piers from a load (fig.1).

It is difficult to arrive at unified solutions during construction, for strengthening of all piers of outer longitudinal walls is required.

A different method of strenghening brick walls in their plane has been worked out by the present writers. The method is based on transferring the seismic load in the wall plane to the extreme corner piers (and in long buildings - to the extreme and to one or two intermediate piers), thereby relieving all the intermediate piers from a load.

The method is essentially based on the data of experience of earthquakes and design analysis of buildings. From these data it has been ascertained that seismic load in the wall planes is distributed between piers in proportion to their regidities, thanks to the non-deformity (in the horizontal direction) of the above-opening masonry band strengthened with a floor imbedded in it.

This was graphically substantiated by the earthquake in Ashkhabad. The extreme (and), Wider piers were subjected to the effect of the predominant part of seismic load in the wall planes. Not differing in material from that of intermediate piers they did not withstand the load and collapsed (Fig.2). Almost in all of the new buildings the width of the extreme piers was larger than of the intermediate ones, for it conformed with the requirements of Earthquake-Proof Building Regulations in the USSR, valid up to 1962.

In 1962, when norms were reconsidered, the requirement for increasing the width of extreme (and) piers was excluded from the Regulations, this being based on investigation of the stressed state of walls under the influence of seismic forces in their plane, and on taking into account of the after effects of earthquakes as well. The provisions of the new Regulations required that the width of extreme piers of the inner size should not exceed the width of intermediate piers.

This change in the Regualtions was well-grounded. With the same strength of piers, the extreme ones, owing to their greater width, could not be allowed to bear the predominant part of seismic load. The principle[III] according to which the stiffer elements must therefore have more strength could not be disregarded. It is this principle that is used in our proposals. We now revert to the requirement that the extreme piers be wider than the intermediate ones, but at the same time propose that the extreme piers be made of material capable to withstand the load they are subjected to.

A concrete with broken brick is the most suitable material for this purpose. The advantage of this material in comparison with the ordinary heavy concrete, is that, being sufficently stiff and durable, it has a lesser coefficient of thermal transmission ($\lambda = 0.5$) and smaller weight ($\gamma = 1600-1700$ kg/cu m). The modulus of elasticity of concrete with broken brick is 5 times larger than the modulus of brick masonry. Therefore, the load on the extreme piers will be 20 times as large as on the intermediate ones (not including the side walls adjoining the extreme piers) if the width of the extreme piers is taken to be, e.g., 1.5 times as large

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1 III) This principle was first formulated by prof. Naito.

as the intermediate ones (Fig.3). This practically means that the intermediate piers are eliminated from the work and thus do not require any strengthening. With a wall length of more than 20-25 m it is necessary, in addition to the extreme piers, to make one or two intermediate piers in a contiguity with inner walls as the elements receiving the load and hence being stiff as to size and material.

As already stated above, considering the results of analysis of damage to buildings during an earthquake, as a basic measure to strengthen many-storeyed brick buildings it is necessary to strengthen all the conjunctions of outer walls in addition to providing the extreme piers of outer bearing walls with concrete. This is best achieved by providing reinforced concrete posts in the conjugations (Fig.3). These posts, being connected monolithically with reinforced concrete bindings and bands, substantially increase the resistivity of the building to the seismic effect. It should be emphasised that in cases adequate quality of masonry is an indispensable condition of seismic stability of the buildings being strengthened.

To strengthen buildings the following measures, in a complex, are to be provided: strengthening of the connection between the outer non-bearing walls and posts with the aid of horizontal reinforced joints at the level of lintels and window sills, and strengthening crosswalls with horizontal reinforcement, where needed conformably to the design, for the crosswalls to receive the main tensile stresses.

The effenciency of wall strengthening according to the method proposed by us depends on the degree to which joint work of the reinforced concrete posts and the extreme concrete piers with brick masonry is provided for, inasmuch as the difference in deformation properties of concrete and masonry may lead, at a certain value of compression, to formation of cracks among them.

Experimental study of contiguities of inner crosswalls with outer walls has been carried out in the USSR in order to estimate the value of the difference of deformations in the conjugated walls of different materials at which joint work is ensured and cracks do not appear.

Experimental values of the permissible difference of free wall deformations for buildings with various numbers of storeys are given in Table 1.

The crack-stability of masonry conjugations of various materials in the upper storeys of buildings are checked under the assumption that the respective sections of walls are not connected with one another and are freely deformed under the load.

Table 1

Number of storeys	Δ permissible in mm
5	8
6	9
7	10
8	11
9 and more	12

The initial modulus of elasticity for "100" mark concrete of broken brick $E_o^{\delta} = 110,000$ kg/sq cm.

The initial modulus of elasticity for reinforced brick masonry with mortar of mark "50" equals $E_o^{k} = 100 \times 30 = 30,000$ kg/sq cm.

The absolute relative deformation of masonry, with allowance for creep, is determined by the formula

$$\varepsilon = \gamma \frac{6}{E_o^{k}}$$

where the coefficient of creep γ for brick masonry is taken to be equal to 2.2, and for concrete to 2,9.

The mean value of compressive stress is determined under the assumption that in the lower section of the wall the stress in the masonry is equal to the calculated stress, and in the upper section it equals zero.

Then for a 5-storey building, 16 m high

$$\Delta = \frac{2.2 \frac{15}{2} \times 1600}{30000} - \frac{2.9 \frac{15}{2} \times 1600}{110000} = 8.7 - 3.2 = 5.5 < 8$$

Thus an approximate calculation shows that the obtained difference of free deformations between reinforced concrete and masonry is permissible.

The conditions for joint work of wide concrete piers (or reinforced concrete posts) and brick masonry are actually favourable, for the connection between them is strengthened with the aid of the toother and reinforcement edges. The edges of the toother are recommended to be laid in the height of 3 brick rows and of half-brick in depth (Fig.4). It should also be borne in mind that the conjunction between wall sections of various materials is not a through one all along the height of the building. Within each storey it is interrupted by a reinforced concrete binding, that distributes the load on masonry in the conjunction zone and serves as a barrier against the spreading of cracks from storey to storey.

The experience of utilization of complex reinforced concrete constructions in Bulgaria, Yugoslavia and other countries shows that cracks do not usually appear at the contact of masonry with reinforced concrete inserts.

Brick buildings strengthened with concrete posts in the mutual conjugations of the outer and inner walls may not to be classed as framed ones, for the linear stiffness of cross-bars is so much less than the linear stiffness of posts-when each storey of building is 3 m high and the distance between walls is 8-10 m; with reinforced concrete bindings of 12 x 22 cm or 24 x 22 cm in section and posts of 38 x 38 cm in section - that the connection of cross-bars with posts should be considered as being hinged.

The crosswall strengthened at their ends with reinforced concrete posts essentially involve cantilever constructions with double reinforcements subjected to eccentric compression of great eccentricity. The common work of the elements of constructions up to the point of collapse is ensured by the solidity of connection of reinforced concrete posts with brick masonry, due to the presence of a toother in the masonry and reinforced edges, whereas in the side walls subjected to the danger of toppling, common work is furthermore ensured by the presence of continuous horizontal reinforcement fixed with its ends in the posts.

In some cases the reinforced concrete posts have to be arranged in the conjugations of not only the outer but of the inner walls as well. Such a case may occur, for example, when the staircase is to be enclused within non-continuonus walls. The reinforced concrete posts should be arranged in the conjugations of these walls with the inner longitudinal wall in order to eliminate dissymetry in the position of posts and to ensure unidurability of the staircase walls (Fig.5).

Arrangement of reinforced concrete posts in all wall conjugations as a measure to strengthen many-storeyed buildings is resorted to in the Federal People's Republic of Yugoslavia.

The posts are positioned at a distance not exeeding 4 to 4.5 m, this permitting consideration of building as a framed one (Fig.6).

Buildings with walls of correct-form stone and strengthened by reinforced concrete posts are constructed in Barca (Cyrenaica, Libya). As to the manner of execution they are complex constructions. In Barca some one-storey buildings strengthened with reinforced concrete posts and bands were still under construction, and yet they withstood the earthquake of 1968 without substantial damages (Fig.7).

The construction of brick-building strengthening with the aid of reinforced concrete posts, used in a number of structures in Tbilisi is given in Fig. 8.

The crack-stability of horizontal joints may be substantially increased if compression in them is generated by means of a prestressing of the reinforcement. In the USSR, the proposals for prestressing reinforced-stone constructions were elaborated by N.A. Slovinski and Y.A. Izmailov, Candidates of technical sciences.

Prestressing is not compulsory, for the seismic stability of many-storeyed buildings is sufficiently ensured by vertical reinforcing or complex reinforced concrete constructions. Prestressing is recommended in cases in which it is necessary to ensure high safety and solidity of the building and to eliminate the possibility of formation of cracks in the walls during earthquakes. Designing prefabricated reinforced concrete structures was given special attention at the Vth International Congress on Prestressed Reinforced Concrete in Paris,1966. The general conclusion from the contributions of Congress participants and from experience of utilization of prefabricated constructions in seismic areas was formulated to the effect that these constructions may be considered as monolythic ones only provided that they are connected by means of prestressed reinforcement.

From the view-point of construction designing against seismic effect it only the strengthening of walls by arranging reinforced concrete posts in all the conjugations of the outer walls with inner walls that is of interest among the foregoing methods of strengthening brick buildings. Strengthening of walls by providing stiff extreme (and) piers of concrete does not involve any specificities as to design and therefore is not considered by us.

Brick walls, strengthened with reinforced concrete posts at their ends (in the corners and in contiguities of inner walls with the outer ones) and subjected to the influence of bending or eccentric compression with great eccentricity should be designed as walls mounted with double reinforcement in the base of the cantilever (Fig.9).

In order that the design of walls be sufficiently substantiated in above assumption it is necessary to ensure the common work of reinforced concrete posts and brick masonry up to the moment of the construction collapse. This is achieved by erecting posts conformably to the above method, i.e., by leaving the toother in the masonry of the wall in the masonry casing on the side of strengthened wall, and by strengthening the connection between the concrete and the masonry with the edges of horizontal reinforcement.

Collapse of brick walls strengthened in this way may occur when the supporting capacity of both the compressed and the extended part of the cross section is exhausted. Thus, it is necessary to ensure the strength of the construction in either case.

As is known during eccentric compression with great eccentricity

$$\frac{S_x}{S_o} \leqslant 0.8 ,$$

where S_x - is the statical moment of the compressed part of the cross-section relative to the extended reinforcement;

S_o - is the static moment of the total cross-section relative to the same reinforcement.

In this case calculation against the eccentric compression of the cross-section is derived by the formula

$$N \leqslant \gamma(1{,}05 R F_{KC} + 1{,}25 R_{np} F_{bc} + R_a F'_a - R_a F_a) \qquad (1)$$

The position of the neutral axis is determined from the equation

$$1{,}05 R S_{KCN} + 1{,}25 R_{np} S_{bcN} \pm R_a F' l_1 - R_a F_a l = 0 \qquad (2)$$

In the formulae (1) and (2)

R - is the computed strength of compression of non-reinforced masonry;

R_{np} - is the computed strength of axial compression of concrete ;

R_a – is the computed strength of reinforcement;

F_{kc} – is the area of the compressed part of masonry;

F_{bc} – is the area of compressed concrete ;

S_{kcN} – is the static moment of compressed part of masonry relative to the point of the application of force N ;

S_{bcN} – is the static moment of compressed concrete relative to the same point;

ℓ and ℓ_1 is the distance from the point of force application to the centres of gravity of the reinforcement F_a and F'_a ;

φ – is the coefficient of longitudinal bending at the elastic characteristic α for non-reinforced masonry.

In the formula (2) the plus sign is adopted if the longitudinal force is applied beyond the limits of the distance between the centres of gravity of reinforcement F_a and F_a , and the minus sign – if this force is applied between the centres of gravity of reinforcement.

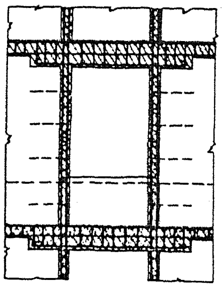

Fig. 1 STRENGTHENING OF PIERS AND LINTELS OF BRICK BUILDINGS

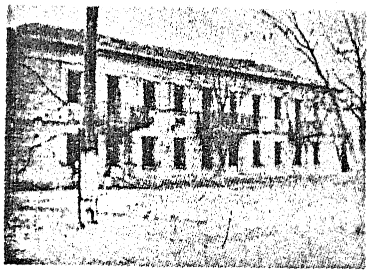

Fig 2 CRACKS IN THE EXTREME PIERS

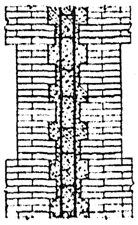

Fig. 4 ADJOINING OF REINFORCED CONCRETE POSTS TO THE MASONRY

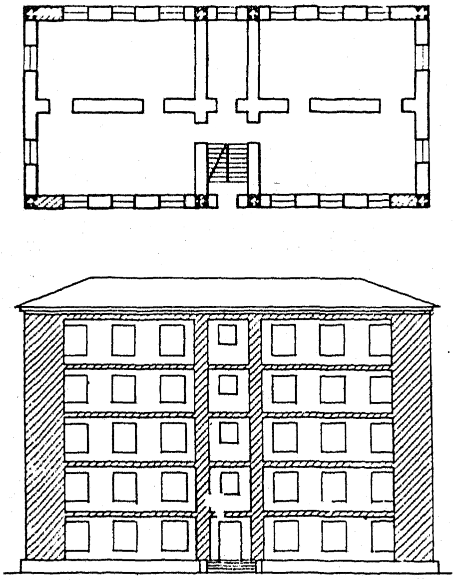

Fig. 3 PLAN AND ELEVATION OF BRICK BUILDINGS STRENGTHENED ACCORDING TO THE AUTHORS' METHOD

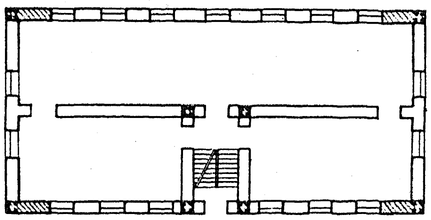

Fig. 5 STRENGTHENING OF NON-THROUGH WALLS OF STAIRCASE

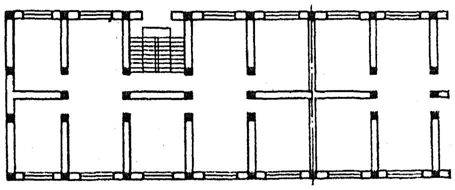

Fig. 6 STRENGTHENING OF BRICK BUILDINGS WITH REINFORCED CONCRETE POSTS AS IT ACCEPTED IN YUGOSLAVIA

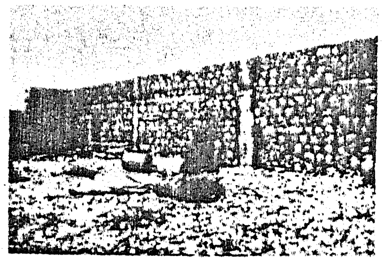

Fig 7 MASONRY STRENGTHENED WITH REINFORCED CONCRETE POSTS AND BELTS

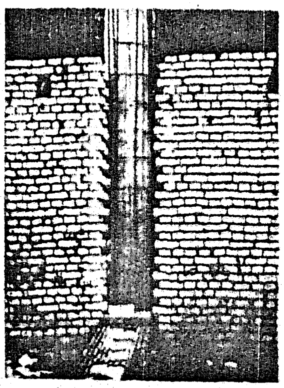

Fig. 8 STRENGTHENING OF BRICK MASONRY WITH REINFORCED CONCRETE POSTS

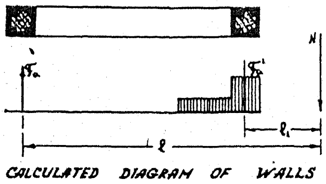

Fig. 9 CALCULATED DIAGRAM OF WALLS STRENGTHENED WITH REINFORCED CONCRETE POSTS