RESTORATION OF STONE BUILDINGS AFTER EARTHQUAKE

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Abstract

One of the features of Tashkent earthquake 1966 is that all buildings located in the epicentral zone had been heavily damaged but not destructed. From here the problem of repair-restoration works arose in an unprecedented scale. For this purpose the designs had been quickly worked out and the albums of standard constructions for the restoration of buildings were given to engineering organizations.

The brick abutments with cement solution were applied for the reinforcement of one-storeyed adobe buildings.

The restoration of multistoreyed buildings were produced by two ways. The arrangement of steel networks covered with the layer of gunite on both sides of damaged walls and wide piers have got the most application.

Many buildings were reinforced by steel belts of round and rolled steel. In some buildings the two ways were applied in common.

The control of the efficiency of the restoration works was produced by instrumental methods on the base of the measuring of the dynamical rigidity of buildings. The interesting data on the measuring of the rigidity of the restored buildings after strong aftershocks have been obtained.

1. PROBLEMS AND METHODS OF RESTORATION.

In the central part of Tashkent brick wall buildings have been seriously damaged by the earthquake of April 1966. Among these there were dwellings, schools, childcare and medical institutions, municipal buildings, educational and trade establishments and a number of industrial enterprises. More than 84000 flats, 225 children's homes, 181 schoolhouses have become completely out of conditions. Many thousands of families were left homeless and the normal functioning of state institutions was disturbed.

An urgent necessity arose to rehabilitate the housing resources and reinsure the operation of institutions in the shortest time. It would be quite impossible to replace all damaged buildings by new ones in short time, therefore it

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was decided to repair the existing structures.

Necessary constructive measures depend upon the character and extent of damage. In this regard the following classification of damages may be introduced:

1) Local break-down of masonry of former doorways and embrasures later on filled up with brick, of architectural decorations, cornices, parapets, porticos also ovens and chimneys, plasters and relief ornaments of walls and ceilings. In this case the main supporting walls of a building were in a sufficiently good condition and the bonds in corners and intersections of walls remained intact. This is a slight degree of damage, giving no difficulties for repairing.

2) The general kind of damage which not less that half of all wrecked buildings were subjected to, is destruction of supporting walls and piers. It consists in origination of great number of sloping cracks, inclined at the angles of 30° to 60°, intersecting cracks and horizontal cracks, situated at different levels and splitting brickwork at full cross section. These cracks mainly affected the joints of brickwork but in any cases splitted bricks also. Injuries of the first kind, described above, were present but the bond of walls remained intact or had only local failures. Such degree of damages may be characterized as the loss of bearing capacity of walls and piers and intactness of the general structure of a building. In this condition were many buildings formerly and newly erected, one- or many-storeyed. Multistory buildings were damaged chiefly in two upper floors, lower floors remaining in much better conditions. There were however some cases of prevalent cracks in lower floors. Both floors of two-storey buildings often were equally injured.

3) In about a fourth of all wrecked houses besides the failures, described above, there were additional failures in form of breaks of bonds between perpendicular walls e.g. in corners and intersections of inside and outward walls.

Such defects occured in one-storey buildings, having no aseismic constructions, but there were a number of multistory buildings of former erection with the same failures. The vertical cracks were of a small gap and there were no considerable slanting of broken walls out of vertical plane and no visible displacements of walls about adjacent or supported ceilings. Such a condition of a building may be defined as the loss of bearing capacity of supporting constructions (walls and piers) and the break-down of general structure or integrity of a building.

4) In some cases the break of bonds between the walls

was followed by considerable deflection from the vertical plane and the fall of seperate walls or their parts. Buildings in such conditions were considered as completely ruined and as a rule generally were pulled down. Such was the case of one-storey adobe buildings. In multistory buildings this kind of damage was met quite rarely, chiefly in the upper floors.

In some cases by means of demolishing the upper floor and thus lowering the height of building, its conditions were reduced to ones classified above at the item 3.

In other cases only separate rooms or small parts of building were ruined. By pulling down broken wall and replacing it by new one properly jointwith other walls, conditions of the building were also reduced to those of item 3.

Restoration of buildings with damages of first category was performed by ordinary means and is of no interest in relation to the matter in question. However it is to be observed that all the unstable parts of inside and outward decoration were torn down and replaced with simpler and more seismic resistant ones.

Thus the whole range of restoration problems was reduced to solving of two essential questions: a) restoration of the bearing capacity of walls and piers; b) restoration of inter connections of walls and the integrity of a building construction.

Methods of solving these problems depend upon the degree of seismic resistance to be obtained as a result of restoration works.

Seismic resistance of rehabilitated buildings might be suggested to correspond with code requirements for new buildings in Tashkent. Yet there were a great number of buildings raised at the time when there had been no approved aseismic code. Furthermore, there were many buildings constructed in accordance with the former seventh degree of seismicity code. The general design and constructions of these buildings can not be adapted to the enhanced requirements of to-day by means of restoration. For that purpose a complete reconstruction of buildings should be needed. Hence the object of repair works was determined as the increasing of seismic resistance and strength of damaged structures up to their initial conditions if inadequate to the modern aseismic code for Tashkent. Two convincing agreements can be set forth in favour of this decision.

Firstly, the most of buildings existed for scores of years and so they may be proposed to serve over a sufficiently long period of time after restoration.

Secondly, many of buildings endured the seven degree earthquake of 1946 without any important injuries. Earth - quakes of greater intensity such as that of 1966 may happen in Tashkent but very seldom. On this account the construc - tive measures forreestablishment of the initial strength of structures will be sufficient to secure the durability of buildings.

Methods of restorations, based on these premises become clearly defined. Four standard constructions were devised to cover the whole variety of damages, and an album of typical constructions, worked out by a group of specialists, was is- sued as a general guide forbuilding offices.

The following constructions were recommended.

1. For the restoration of bearing capacity of walls and piers the wire networks placed on both sides of the wall and covered by the layers of gunite were taken as the principal construction. The general aim of this reinforcement is to increase the strength of the wall against the lateral forces.

Additional reinforcement of continuous walls and wide piers against the vertical loads was not usually required. If there were large cracks in the wall, the injection of ce- ment mortar under pressure was produced what gives additio- nal increase of strength against shears and vertical loads. The thickness of the gunite layers was defined by special design and usually did not exceed 30-40 mm. The general quantity of reinforcing wire was appointed with such consi- deration that the iron nets under the action of tensile stresses had strength equal that of undamaged wall. On the avarage the tensile and shear strength of steel are approxi- mately 2000 times more than that of brick masonry. Hence the total cross-section of reinforcing net must equal 0,05 % of the area of horizontal cross-section of the wall or 0,025% on each side, that corresponds to a steel net of 5 mm with a 20 cm distance between wires.

2. The procedure described above is available for the continuous walls and wide piers. It is difficult to apply this procedure for the narrow piers and brick posts. Further more it is always necessary to reinforce these elements against the effect of vertical loads. So for reinforcement of these elements the metal casing with vertical bars of angle iron and cross bonds of band or rod iron have been ap- plied. The minimum total area of bars cross-section was de- termined under condition of equivalent strength of metal reinforcement and damaged element but as a rule was taken more than the design minimum.

3. For the restoration of bonds between the perpendicular walls in multistory buildings the adjustment of metal belts of channel iron on both sides of the wall at the level of ceiling slabs was applied. The area of belts cross-section was defined by the equivalent strength with a disturbed vertical joint. The belts were connected between each other by the metal vertical bars.

4. The reinforcement of one-storey buildings with broken joints between the walls was accomplished as a rule by means of external abutments made of brick on cement mortar. Restoration of these buildings was designed for a short time of existance. In many cases for particular buildings some of the four principal constructions were applied in common. Formerly similar constructions of the reinforcement of damaged buildings with brick walls had been applied in seismic districts of Middle Asia (Tashkent, Dushanbe) and proved to be sufficiently reliable.

2. THE ANALYSIS OF THE RESTORATION RESULTS.

To evaluate the efficiency of constructive measures applied let us consider several typical buildings heavily damaged by the earthquake and reinforced accordingly by the methods described above:

a) The buildings restored with the application of metal belts and poles of rolled steel (method 3).

Three forty-flat five-storey brick dwellings with semi-basement series 1-310 H built in 1965 have been observed. These buildings were designed to 8 degree of seismicity. According to the macroseismic data the earthquake intensity was 8 in that district. After the earthquake all buildings have been seriously damaged because of insuffioient quality of masonry. As the damages of these buildings were similar we should analyze only the constructive measures on the reinforcement and the effects of aftershocks on the one of these buildings.

It is known that the free vibration period characterizes the dynamic rigidity of buildings. The damages of buildings lead to the decrease of the rigidity and may be found out by the increase of the natural vibration period.

In the paper 2 the essential effect of building deformability on the value of free vibration period is stated. After earthquake in all these buildings the natural vibration periods have been measured in two directions at several points. The measurement was made by means of investigating the records of microseismic vibrations of buildings caused by the city transport and the working of industrial plants.

In some buildings a momentary relaxation of horizontal load, applied at the level of the upper ceiling, was used to excite free vibrations. In both methods small amplitude vibrations were dealt with and nearly similar results were ob - tained.

On the 24-th of March 1967 the earthquake with intensity 7 occured. After this earthquake in these buildings the de - tail observation and the measuring of the free vibration periods at the same points were produced. The results of the measurings are given in the table 1. From the table it is seen that the natural vibration period after the capital restoration repair has decreased by 18-20 % what is the result of the increase of building rigidity. After the earthquake of 24 March the natural vibration period at the same points has increased by 10-12 %.

In the table 1 the results of damaged building observation after earthquake, the natural measurings of the vibration periods before and after earthquake, after capital restoration works of a number of typical buildings placed in an epicentral zone and restored with the application of metal belts and poles of rolled steel are given.

b) The buildings restored by means of the adjustment of metal networks covered with the gunite on the both sides of damaged walls and piers. The most of buildings were restored by this procedure. The results of observations after earthquake and of natural measurings of dynamical characteristics are given in the table 1.

CONCLUSIONS

1. The metal belts and poles of rolled steel applied for the reinforcement of damaged buildings in the subsequent earthquake come into operation after the appearance of deformations in buildings. Therefore the buildings reinforced by this procedure after the strong earthquakes will require the additional repair works.

2. The building rigidity reinforced by the metal net - works and gunite on both sides of damaged walls considerably increases.

From the table data it is seen that in particular cases the natural vibration period in comparison with the data before and after the earthquake 26 April 1966 increased by 10-15 % and after capital restoration works decreased by 30-40% i.e. the deformed and damaged buildings after restoration became more rigid. The measuring of the free vibration periods of these buildings after the strong aftershocks (see table 1) shows that in this case the constructions of reinforcement come into operation in initial stage of deformation. On this account the preference must be given to the method of gunite. Additional reinforcement of the bonds between the walls must be provided by means of rolled steel belts.

3. Metal casings are needed where there are narrow piers, not more than 100 cm wide, and brick posts, supporting ceilings. It is recommended to reinforce all such elements both damaged by earthquake and intact ones.

4. Brick masonry abutments are very effective for the reinforcement of one storey buildings under the condition that the joints of the masonry be made inclined in the direction of the supported wall. These constructions are recommended for provisional reinforcement as they make worse the outward appearance of buildings and create a number of discomforts during the exploitation.

Besides, the experience shows that their efficiency decreases in time due to the ground deformation and the shrinkage of masonry.

5. According to the data of natural measurements of dynamical characteristics of buildings before earthquake, after earthquake and after the restoration it is possible to estimate instrumentally the deformability of a building and the efficiency of that or the other methods of restoration.

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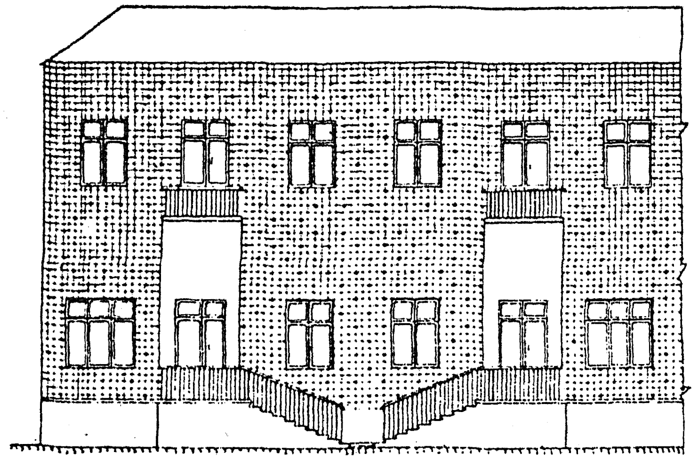
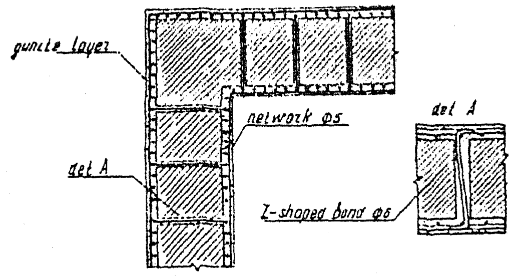
Number	Name and constructive characteristics	Storeys	Aseismic design	A type of damages	Method of restoration	The free vibration periods (sec.)			
						Before earthquake 26IV-66	After earthquake 26IV-66	After restoration	After earthquake 24III-67
1	2	3	4	5	6	7	8	9	10
1.	The brick dwelling	2	8	Sloping cracks in wide piers of the second storey, horizontal cracks at the level of the floor.	I	-	0,35	0,26	-
2.	The brick dwelling	3	-	X-shaped, vertical and horizontal cracks.	I	-	0,32	0,25	-
3.	The brick dwelling	4	-	Sloping and horizontal cracks.	I	-	0,35	0,32	-
4.	The brick dwelling	3	7	In the walls of staircases sloping hair cracks parallel to the flight of stairs.	I	0,25	0,31	0,26	0,29
5.	The brick building with reinforced concrete columns	3	7	The horizontal and sloping cracks in the bearing walls.	I	0,33	0,35	0,30	-
6.	The brick building with reinforced concrete columns.	3	7	X-shaped and horizontal cracks.	I	-	0,25	0,30	0,25
7.	The brick dwelling	4	7	The building was damaged by Chatkalskoye earthquake 1946. After the earthquake 1966 essential horizontal, sloping, x-shaped and vertical cracks.	I	0,27	0,48	0,51	0,48
8.	The brick dwelling	5	8	Numerous x-shaped and horizontal cracks.	III	-	0,39 0,38 0,38	0,32 0,32 0,31	0,36 0,35 0,35
1	2	3	4	5	6	7	8	9	10
9.	The brick dwelling	3	-	The sloping, horizontal and vertical cracks in bearing walls, essential damage of chimneys.	III	-	0,36	0,22	-
10.	The brick dwelling of old construction.	2	-	The building was damaged by Chatkalskoye earthquake 1946. After the earthquake 1966 essential cracks in bearing constructions, broken bonds between walls.	III	0,23	0,3	0,22	-
11.	The brick building of the library.	2	-	The sloping cracks nearly in all bearing walls, broken bonds between walls.	III	0,26	0,36	0,22	-



Method I Façade



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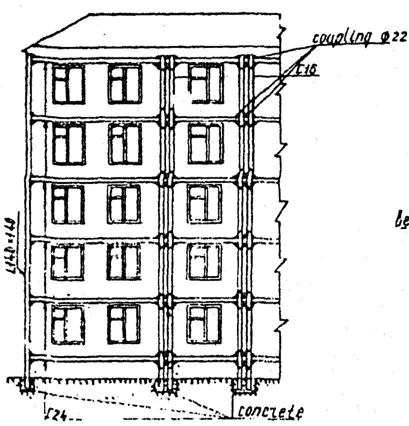

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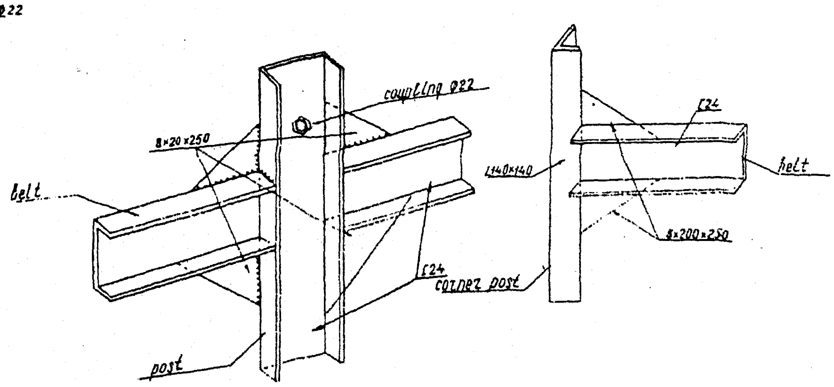

Method III Details