CONSEQUENCES OF TASHKENT EARTHQUAKE 1966 AND TESTING OF RESTORED BRICK WALLS

by

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SYNOPSIS

The observation results of the consequences of Tashkent earthquake 1966 are represented. The important features of observed behaviour of structures and some propositions on the improvement of the building aseismic design are marked.

The questions of seismic stability of underground structures and the influence of the fluid head in pressure pipelines are considered.

The different methods of the test of restored buildings after earthquake are described. In the result of worked out methods the design formula of the destructed and reinforced brick masonry by gunite on horizontal loading has been proposed.

The epicentre of the earthquake coincided with densely populated city regions. The intensity of the earthquake in the epicentral area covering approximately 15 km$^2$ was 8 degrees of 12 degrees seismic scale, adopted in the USSR. A great number of different brick masonry buildings got essential damages but were not destructed which afforded the best possibilities for investigation of seismic effects.

The important features of observed behaviour of structures are following:

The predominant damages took place in the upper stories in two to six story buildings. At a rough estimate 70% of buildings got damages in upper stories. The most typical failures of brick masonry were horizontal cracks in walls and piers mainly in the upper stories and in one-story buildings

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also, at different levels of a story: near the floor, at the lower and the upper edges of window openings, under the ceiling and near the cornice. A great many of slope cracks and comparatively small numbers of intersecting or -shaped cracks, what was obviously due to a very small duration of earthquake, not more than 6 sec., so that only one-sided impacts of great intensity occured.

In the result of the observation analysis some propositions on the improvement of the brick masonry building aseismic design , leading to better agreement of the design with the actual data, have been made. Among these are the following two.

The distribution of the shear force for designing brick masonry constructions was increased at the upper stories so that a seismic load had been defined as proportional to the height of the structure, when formerly the cosine law of distribution had been adopted. The total shear force was left unchanged.

The great effect of the vertical component of the seismic forces was found out and the necessity of due consideration of vertical components in aseismic design of brick walls was established.

Later on the both propositions had been included in aseismic code requirements.

Some important conclusions on the behaviour of underground structures were drawn on the base of detailed investigation and recording of the effects of the earthquake and its most intense aftershocks:

1. The underground structures of pipelines and tunnels type, in principal, are damaged and destructed in the points of their contact to reservoirs, manholes, pumping stations, building foundations, house lead-ins, branchings, near sharp rotations, under the laying out of structures through the rivers, ravines and etc., i.e. near complex joints. The manholes, cameras, pumping stations and etc. have not got essential damages.

2. The joint connection /flanged and belled/ are damaged most of all. The pipelines with elastic joint connections are more aseismic.

3. The soil conditions effect intensely on the work of complex underground structure systems. A great number of damages were in structures, layed in soft soil, and also in the points of soil contact with sharply different physicomechanical properties.

4. The seismic stability of underground structures /pipelines/ depends on the laying depth. The relation of specific

accident rate of pipelines on the laying depth has been stated, which shows that with increasing of laying depth ( to the definite depth) the pipelines seismic stability rises. At the expense of applying of special aseismic measures the limitation on the laying depth need not to put.

5. In pressure pipelines the fluid head, running in the pipe, effects on the seismic stability. The relation of quantity of joint damages from the pressure of water mains have been determined during the aftershocks of Tashkent earthquake, occured in different time of a day, when in mains the sharp variation of pressure have been observed; the more pressure in water mains the more damage quantity.

6. The relation of damages quantity on structure diameter has been stated. The structures with larger diameters are better resisted to earthquake effect and have less average accident rate. It is proved on the example of an iron pipeline.

7. The essential part in providing of aseismic underground structures plays the observance of special requirements during their construction in seismic regions. When under the construction the breach of technical conditions has taken place the pipelines have often got damages. For example, the reasons of damages were: the breach of trench filling by natural soil; the trench filling by constructional rubbish; the absence of condensation in tunnel passages under the aryks and in other places.

8. The damages of underground structures of different appointment caused a definite loss and required corresponding time and material expenditures for their liquidation. From above-mentioned the great problem actuality of motion theory creation of complex underground structure systems follows, answering to the real work conditions of structures under seismic effects.

A great number of damaged buildings in the centre of the city sets up the problem of restoration in an unprecedented scale. For this purpose the designs had been worked out and the albums of standard constructions were given to engineering organizations.

The restoration of multistoried buildings was produced in two ways. The arrangement of steel networks covered with the layer of gunite on both sides of damaged walls and wide piers was applied to most of buildings. Some buildings were reinforced by steel belts of round and rolled steel.

The measurings of the dynamical characteristics of more than 50 restored buildings were taken where similar observations had been carried out before the earthquake.

The efficiency of the two methods of restoration was estimated by comparison of dynamic characteristics, received before and after the earthquake, after the restoration and after strong-motion aftershocks. The method of steel networks with gunite layers proved to be the most effective.

For the direct determination of masonry strength after restoration the experimental investigation of brick wall fragments in full scale has been produced on the specially constructed testing assembly. Brick wall fragments of 165x x 165x40 cm and 845x320x40 cm size, rigidly fixed at the base, have been subjected to the horizontal force in the plane of the wall applied near the upper end. The force gradually was increased till the appearance of cracks in the masonry. Thereby the diagonal cracks appeared which were like those in the piers and crosswalls of buildings subjected to the earthquakes. Fig. 1 The damaged masonry fragments had been reinforced by the steel network with the subsequent gunite coating and subjected to repeated testing.

The comparison of wall strength at the first and the second tests gives the possibility to estimate the restoring constructions effectiveness. Besides the direct measurement of the masonry resistance, the natural vibration periods of wall fragments were defined at several stages of testing: before and after the first testing, after restoration and after repeated testing. The mass of wall fragments being constant, the vibration periods depend only on their rigidity. The comparison of periods after each testing allows to define the changes of the fragments rigidity after their failure and restoration.

The first series of fragments represented square piers of 165x165x40 cm size, without adjacent parts of wall, lintels or reinforced concrete belt.

The horizontal force testing was carried out without additional vertical loading of fragments.

The specimens of the second series of the size 255x x 200x 40 cm represented the piers with adjacent parts of window lintels and reinforced concrete belts.

Before the beginning of the test by horizontal force the constant vertical load was applied in two variants: 3,5 tons and 20,0 tons on each pier. The first load corresponds to the abovelying structure pressure on the pier of the highest story and the second - on the pier of the first story of 4-th storied dwelling house with transverse bearing walls.

The third type of specimens is the fragments of brick walls of 4-th storied dwelling house, designed for 9-deggrees seismic zone. (Fig. 1.2).

The tested fragments consisted in three piers with the total size 840 x 320 x 40 cm.

Before the beginning of the test the specimens of this type as well as the 4 second type specimens were loaded by the constant vertical load in 3,5 of ton on each pier.

The test load in the testing assembly has been produced by the hydraulic jack with monometer, graduated in $kg/cm^2$.

Besides the testing forces, the specimen deformations were also recorded. The compression and tension deformation of the pier diagonals have been measured by tensometers and indicators.

The tensometers have been also used for the determination of deformation of horizontal masonry layers in the plane of the wall. The angles of rotation of the upper edge section have been determined by means of indicators. The specimen bendings (deflexion from the vertical) have been measured by deflectometers and indicators.

After the primary test of all specimens these ones were restored by means of the same constructive-technologic method as in the damaged buildings after Tashkent earthquake 26 April, 1966.

From the specimen surface the plaster has been scrapted and for the better adhesion of gunite with brick (cement sandy mortar 1:2) the masonry joints have been cleaned in 1,5-2 cm depth. Then through the masonry joints in chess order the open holes 2 cm in diameter have been drilled. The distance between the holes are 60-70 cm. Through these holes the reinforcing rods Ф6А-I have been inserted and then on the specimen surface the wire net with cells 15 x 15 cm have been placed.

In the third type of fragments (two fragments) the wire net has been also used Ф4А-I with cells 15 x 15 cm.

For the determination of commen deformations of reinforcement (net) with masonry and gunite, in fragments of the third type on the reinforcement the strain gauges have been installed, 48 strain gauges on each fragment.

The analysis of test results.

On the table 1 the principal test results of specimens are shown. In the columns 8 and 9 the loads of primary test are given under the appearance of the first crack and the fragment destruction.

In the columns 10, 11 the loads are given respectively under the appearance of the first crack and under the destruction of restored and repeatedly tested fragments.

In the columns 12 and 13 the load relations are given respectively under the appearance of the first crack and under the destruction during the first and repeated tests. These relations can be called as "coefficients of restoration of bearing capacity" according to the conditions of appearance of the first crack and destruction. The analysis of all these data shows that the abovewritten method of restoration of brick walls not only completely restores the strength and bearing capacity of walls but rather increases it in comparison with initial one.

Analysing the data of carried out investigations it should be noted that the written structure and building restoration technology, destructed during the strong-motion earthquakes, increase the initial pier strength from 1,8 to 3 times.

Hence, for the solution of the problem of damaged buildings restoration this method can be used with a full assurance in its reliability.

The results of carried out investigations of buildings damaged by Tashkent earthquake and restored by gunite and of the structure fragments allow to recommend the working out of projects of earthquake resistant brick buildings with using the metal nets with following guniting in the regions of stress concentration.

The design of the damaged brick masonry, reinforced by gunite has been carried out and the formula has been proposed:

$$N^{n}_{heq} = 0.5 m_s R^{n}_{sh} \left(0.7 F_m + m_c \frac{R^{n}_{c}}{R^{n}_{m}} F_c\right) + m_z R^{n}_{z} \frac{p}{100}$$

where
- $m_s$ – the coefficient, characterizing the masonry state ( intact or destructed),
- $m_m$ – the coefficient of work condition for multi-layer brick masonry,
- $m_c$ – the coefficient, characterizing the work of gunite layer,
- $m_z$ – the coefficient, characterizing the work of the reinforcement,
- $R^{n}_{c}$ – compressive strength of the pneumo-concrete,
- $R^{n}_{z}$ – normative reinforcement resistance

$R_m^n$ - compressive strength of brick masonry,
$F_m^m$ - the area of horizontal section of brick masonry,
$F_c$ - the area of horizontal section of gunite layers,
$F$ - the total area of horizontal section of brick masonry with consideration of gunite layers,
$\rho$ - per cent of masonry reinforcement on the volume under square net cells produced from reiforced steel.

The results of all kinds of testing show, that the reinforcement of damaged brick walls with steel network and gunite layers provides for a sufficient seismic resistance of buildings.

| 1<br>NN fragment type | 2<br>pier size | 7<br>vertical load, tons | 8<br>horizontal load, tons | 9 | 10 | 11 | 12<br>Coefficients of restoration | 13 |
|---|---|---|---|---|---|---|---|---|
| | | | first testing | | repeated testing | | | |
| | | | 1-st crack appearance | destruction | 1-st crack appearance | destruction | 1-st crack | destruction |
| I/I | I60xI60x38 | - | 6,9 | 8,2 | II,9 | I8,5 | I,72 | 2,25 |
| 2/I | I60xI60x38 | - | 7,3 | I0,5 | I3,6 | I8,7 | I,86 | I,78 |
| 3/I | I60xI60x38 | - | 8,I | II,4 | I6,8 | 25,2 | 2,7 | 2,2I |
| 4/I | I60xI60x38 | - | 8,4 | I0,8 | I5,5 | 25,8 | I,84 | 2,49 |
| 5/I | I60xI60x38 | - | 8,9 | I3,0 | I9,8 | 27,9 | 2,22 | 2,I4 |
| 6/I | I60xI60x38 | - | 9,I | I2,7 | 22,8 | 32,7 | I,39 | 2,57 |
| 7/I | I60xI60x38 | - | 9,6 | I3,7 | 2I,7 | 30,6 | 2,26 | 2,23 |
| 8/I | I60xI60x38 | - | 9,5 | I4,5 | 22,I | 32,0 | I,52 | 2,2I |
| I/2 | I40xI40x38 | 3,5 | 5,8 | 7,2 | I8,7 | 26,8 | 3,22 | 3,72 |
| 2/2 | I40xI40x38 | 20 | 6,2 | 7,2 | 20,I | 28,9 | 3,24 | 4,0I |
| 3/2 | I40xI40x38 | 3,5 | 6,0 | I0,8 | 2I | 30,8 | 3,5 | 2,85 |
| 4/2 | I40xI40x38 | 20 | 9,6 | I5,6 | 2I | 30,8 | 2,I9 | I,97 |

| I | 2 | 7 | 8 | 9 | I0 | II | I2 | I3 |
|---|---|---|---|---|---|---|---|---|
| 5/2 | I40xI40x38 | 3,5 | 2,4 | 7,2 | I8,5 | 25,2 | 7,7 | 3,5 |
| 6/2 | I40xI40x38 | 20 | 4,8 | I0,8 | I8,7 | 26,8 | 3,9 | 2,48 |
| I/3 | 840x322x38 | I0,5 | 2I,6 | 36,5 | 25,2 | I08,6 | I,I7 | 3,06 |
| 2/3 | 840x322x38 | I0,5 | 23,0 | 36,0 | 26,I | II2,6 | I,I4 | 3,22 |
| 3/3 | 840x322x38 | I0,5 | 20,8 | 35,8 | 26,8 | II5,8 | I,29 | 3,24 |
| 4/3 | 840x322x38 | I0,5 | 22,3 | 37,0 | 28,0 | II8,5 | I,25 | 3,20 |

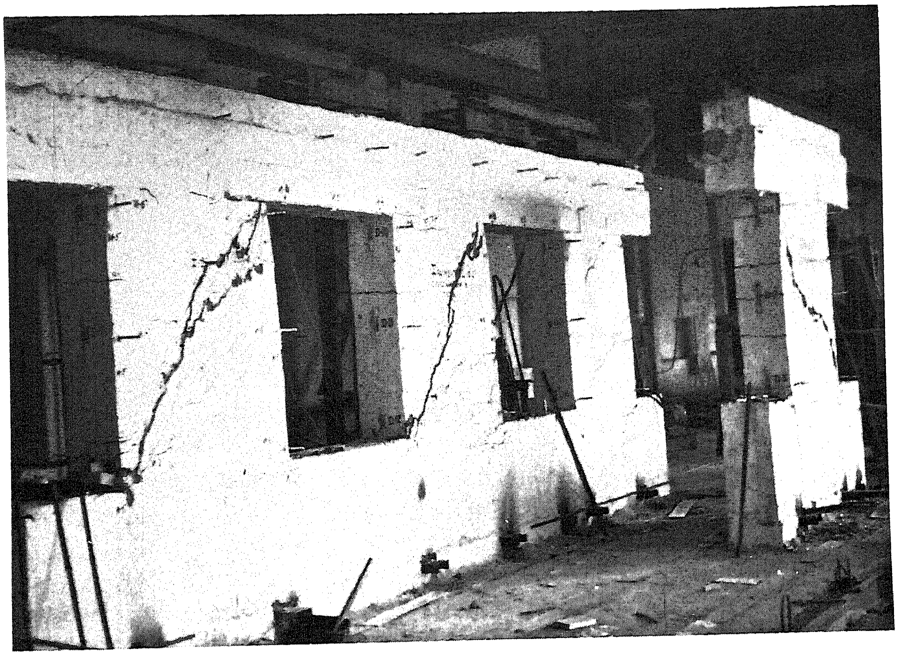

Fig. 1. Third type fragment after first testing.

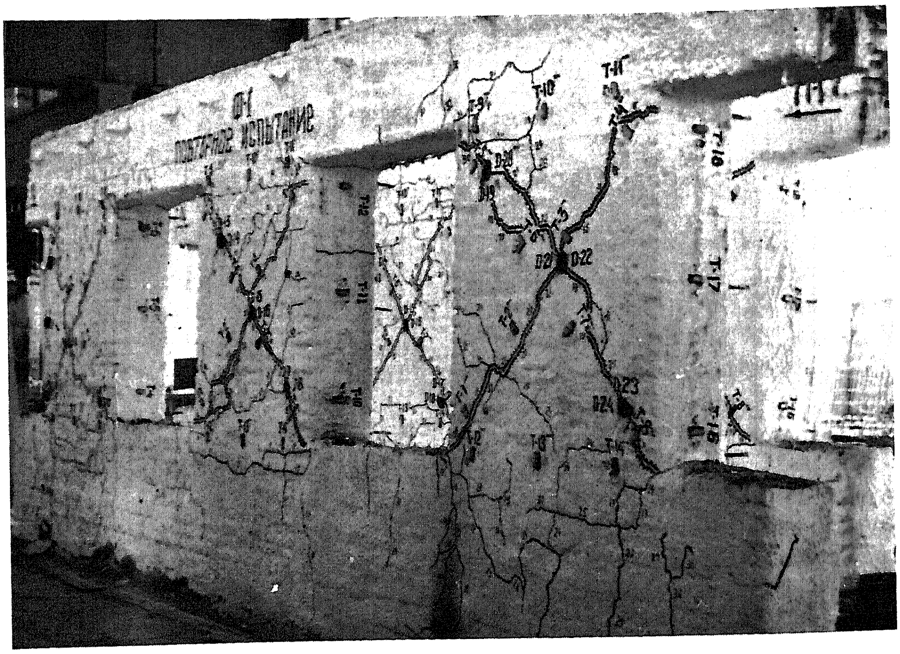


Fig. 2. Third type fragment after repeated testing.