STRENGTHENING OF DAMAGED MASONRY BY REINFORCED MORTAR LAYERS

by

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SUMMARY

The test results of a two-story fragment of a building with brick walls for static and dynamical horizontal loads are presented in this paper. At the first stage of the tests the change in the dynamical characteristics of the building fragment in the process of damage accumulation in its members was studied, the values of a horizontal static load during cracking in masonry and the maximum horizontal load applied to the fragment were determined.

At the second stage of this study the damaged brick masonry was strengthened by reinforced mortar layers 2.5cm thick and repeated fragment tests with static and dynamical loads were conducted. The effectiveness of masonry strengthening using the above mentioned method is estimated by means of comparing the strength and dynamical characteristics of the fragment obtained at the first and second stages of the tests.

INTRODUCTION

Buildings with walls made from small unit materials - bricks, natural and man-made stones are widely spread over various regions of the Earth. Analyses of large earthquake effects evidence that the greatest damage due to seismic influences appeares just in such buildings and structures. A great number of horizontal, diagonal and cross cracks which decrease the structural capacity to resist the following seismic shocks and prevent structures from normal maintenance are caused in the walls of brick and stone buildings even due to moderate earthquakes with intensity 6-7. The necessity for carrying out restoration repair of damaged buildings practically arises after every large earthquake. In these connection the choice of the method for strengthening damaged structures which provides the necessary strength to a repaired structure, minimum costs and the least terms of rehabilitation work seems quite important.

When coping with the after-effects of the 1966 Tashkent earthquake a great number of damaged brick buildings were strengthened by double-sided reinforced hoops of fine concrete [1]. The conducted study [2,3] shows the possibility

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for complete strength rehabilitation of masonry using this method of its strengthening. The strength and stiffness of masonry strengthened by reinforced layers depends on the strengthening layers thickness and the cement mortar strength, the reinforcement quantity and the means of its bonding with a wall, the degree of masonry damage[4]. These factors must be considered in the design as they significantly influence the structural costs and the terms of conducting the rehabilitation work.

The possibility for the carrying capacity rehabilitation of damaged masonry strengthening it by reinforced mortar layers only from one - exterior - side of a building unlike the generally used double-sided strengthening was studied in our experiments.

COMPOSITION OF EXPERIMENTAL WORK

Strength and dynamical characteristics of structures made of usual and strengthened masonry were studied during the tests of a two-story building fragment with brick walls and of a complex structure, subjected to horizontal loads. The tests consisted of the two main stages. At first the fragment of the building with usual brick walls was tested applying a gradually increasing static horizontal load. At the end of the first stage damage of the walls obtained such a degree that the increase of a horizontal load became impossible. After that the individual areas of the brick walls were strengthened by reinforced mortar layers from the outside and repeated tests were carried out. The dynamic characteristics of the building at various degrees of damage in its members were determined in the test process of the fragment subjecting to the static horizontal loads.

Fragment structure. The building fragment is constructed in the form of two brick walls 705cm long, 560cm high and 38cm thick with window openings 120cm long and 150cm high. At the elevations of 2.9 and 5.6m the walls are connected with each other by cast-in-situ reinforced floor slabs 10cm thick. Reinforced lintels 160cm long, 38 by 20cm in cross-section combined with the floor slabs are located over window openings. Along the window openings edges and walls ends masonry is strengthened by reinforced concrete inclusions 13 by 14cm in cross-section, everyone of which is reinforced by two bars ø 12 A-II. Reinforcement elements of these inclusions are connected with each other over 7 masonry layers by the steel ø 6 A-I, embedded into the horizontal mortar joints.

The experimental building fragment is constructed on a rigid undeformed foundation, where vertical steel of reinforced inclusions is fixed. The structure of the fragment with unstrengthened walls is given in Figure 1.

After the first stage of the testing masonry of the low floor from the exterior side was strengthened by reinforced mortar layers 2.5cm thick. At first four ended piers were strengthened and after their repeated failure two middle piers were strengthened. The structure of damaged masonry strengthening is given in Figure 2. The ended piers were strengthened along the diagonals by reinforcing cages consisting of three bars ø 5 B-I (R_r = 495MPa, the reinforcement area to the masonry area ratio $\Sigma f_r/F_m = 2\cdot10^{-4}$) and the middle piers were strengthened by reinforcing fabrics with a mesh of 20 by 20cm (8 ø 5B-I, $\Sigma f_r/F_m = 3\cdot10^{-4}$). Reinforcement of strengthening layers was fixed to the masonry surface with the help of n-shaped steel bars ø 8 A-I, driven into the mortar joints.

Materials. Masonry of the walls consisted of low strength clay bricks with the ultimate compression strength R = 5.5MPa and the ultimate bending strength R_b = 3.1MPa using the cement-lime mortar with the ultimate compression strength R_2 = 5MPa. Average normal masonry cohesion was R_m = 0.18MPa. The masonry ultimate strength R = 2.4MPa and the initial modulus of elasticity R_{0m} = 1950MPa were found from the results of the checking masonry specimen tests of the central compression.

Steel of the vertical reinforced inclusions ø 12 A-II had the yield point σ_y = 300MPa, the ultimate strength σ_u = = 580MPa and the modulus of direct elasticity $E_r = 2.02\cdot10^5$MPa. Horizontal steel in masonry and floor slabs had σ_y = 230MPa, σ_u = 420MPa and $E_r = 2\cdot10^5$MPa, correspondingly.

Concrete of all the elements had the ultimate compression strength R_c = 19.5MPa and the initial stress-strain modulus E_{0c} = 21560MPa. The cement-lime mortar of the strengthening layers had the ultimate compression strength R_m = 10MPa.

Test techniques. Building fragment tests prior and after strengthening were conducted using the common techniques. Prior the tests the ballast was put onto the floors of the ground and first storeys. Taking into account the dead weight of the structure in the bottom levels of the window openings of the ground and first storeys the compressive normal stresses of 0.14 and 0.065MPa were produced in masonry. The set-up of the fragment test is given in Figure 3. Static tests were conducted using the hydraulic jack (2) with the maximum force of 2000kN which was fastened to a powerful supporting pier (3) and transmitted the pressure to the fragment through a steel beam (4) 800mm high. The load to the fragment was applied at the levels of the reinforced floors. The jack axis was at the elevation of 4.97m, thus the horizontal force was distributed between the floors of the ground and first storeys with the 1 : 2.2 ratio. The horizontal load was raised step by step, 60kN per one step. Masonry deformation along the piers diagonals was determined at each stage of loading. The parameters of free and induced vibrations of the fragment were measured prior the tests and also after applying the horizontal load of 295, 590, 785 and 910kN. In addition, the fragment was released from the horizontal load. Vibrations of the fragment were induced with the help of a vibro-machine, instantly throwing down the horizontal load of 60kN and stroking with the load of 4kN at the level of the ground floor.

FRAGMENT STATIC TEST RESULTS

In the process of the static tests on the fragment the character of damage development in masonry and strengthening units was studied, the ultimate values of the horizontal force applied to the fragment made of usual brick masonry and masonry strengthened by reinforced mortar layers weze determined.

Strength of the fragment walls prior strengthening. The fragment elements preserved their integrity when the horizontal load was raised to Q = 530kN. The cracking process in masonry and reinforced inclusions of the ground floor began at the tenth stage of loading under Q = 590kN. Simultaneous cracking in both walls along the A and B axes was observed. In masonry joints of the ended piers up to 4 individual cracks 25–40cm long appeared, the lower ones of which appeared at the elevation of +1.0m at the bottom level of the window openings. One crack about 50cm long appeared in the masonry joints of the middle pier of the A wall in the upper corner of the left window opening. The opening width of the first cracks was 0.1–0.2mm when raising the load up to Q = 705kN. When the horizontal force was raised above 705kN new intensive cracking oriented along the compressed diagonals of the piers began. Most cracks were observed in the ended piers on the side of horizontal force application. The damage character in masonry and ended reinforced elements is given in Figure 4. In the tests on unstrengthened masonry the maximum horizontal load was 910kN. Under that load in one middle pier of the first floor a diagonal crack was produced. The carrying capacity of the ground floor walls was exhausted. The opening width of the diagonal cracks in masonry of the ground floor was up to 5–6cm; the opening width of the cracks in the reinforced inclusions of the low floor was up to 2–3cm. Under the load of Q = 910kN the horizontal steel in masonry was damaged, after what there was observed the beginning of a drop in the hydraulic system and the tests were stopped.

The tests for a static horizontal load were repeated after strengthening four ended piers of the low storey. During the repeated tests small cracks in piers No 6 and 10 appeared under the horizontal load of 350kN and the major diagonal cracks appeared under Q = 705kN. In their location the cracks only partially coinside with the cracks in unstrengthened masonry what indicates the beginning the masonry new piers performance after strengthening. The maximum horizontal load applied to the fragment was 1175kN. Under the load close to the failure one the break of the steel bars in the strengthening layers was observed. Considering the 1.5 times decrease in the piers number withstanding the horizontal load during the repeated tests it is possible to note that the maximum load per one strengthened pier was 1.94 times higher the failure load per a pier from unstrengthened masonry, and the loads at the first cracks appearance were equal.

After failure of the ended piers the tests on the fragment were continued; this fragment had only two strengthened middle piers in the low storey. The first cracks in these piers appeared under the load of 235kN and their complete failure was caused under the load of 880kN. Thus, masonry strengthening by mortar layers with the reinforcing fabrics of a square mesh resulted in the 2.9 times increase of a failure load per 1 pier in comparison with the strength of unstrengthened masonry.

DYNAMICAL TEST RESULTS

Determination of the fragment dynamical parametres - the natural vibration period and the damping logarithmic decrement - was done for monitoring the variations of the fragment stiffness properties at different stages of the structural behaviour. The results of determination of the fragment dynamical characteristics prior horizontal loading (T_1 and δ_1), after the first structural cracking (T_2 and δ_2) and after applying the maximum horizontal loads (T_3 and δ_3) are presented in the Table below.

Structural state	Periods of natural vibrations T and damping logarithmic decrements δ					
	T_1, s	δ_1	T_2, s	δ_2	T_3, s	δ_3
Prior strengthening	0.06	0.55	0.075	0.35	0.105	0.2
Four strengthened ended piers	0.075	0.55	0.08	0.50	0.12	0.27
Two strengthened middle piers	0.095	0.36	0.106	0.36	0.125	0.23

From the data listed in the Table one can see the decrease in the periods of natural vibrations and the increase in the damping logarithmic decrements of the fragment after carrying out the measures on strengthening the masonry damaged areas.

CONCLUSIONS

The results of determination of the carrying capacity and dynamical characteristics of the building fragment of the damaged and then strengthened brick masonry show the possibility for complete rehabilitation of the initial strength and stiffness of brick buildings strengthening them by one-sided mortar layers.

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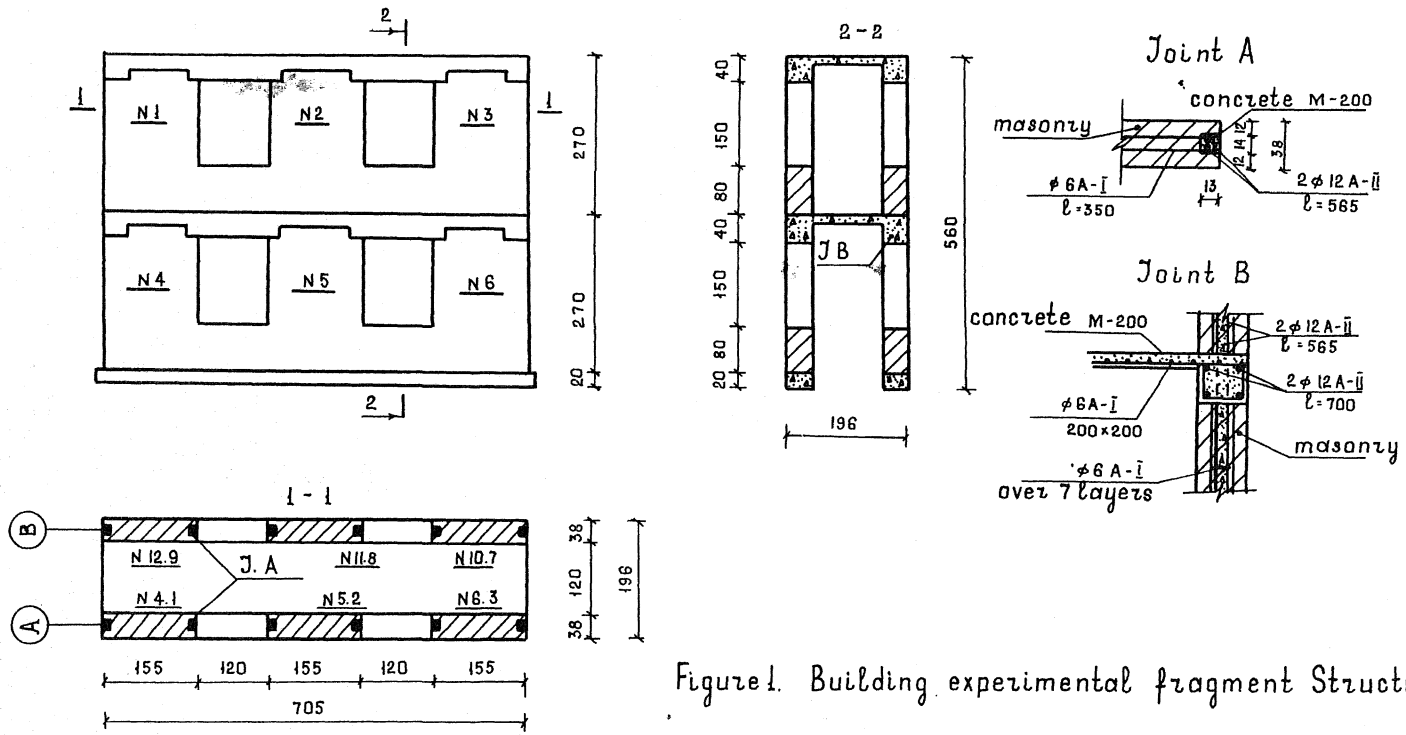

Figure 1. Building experimental fragment Structure

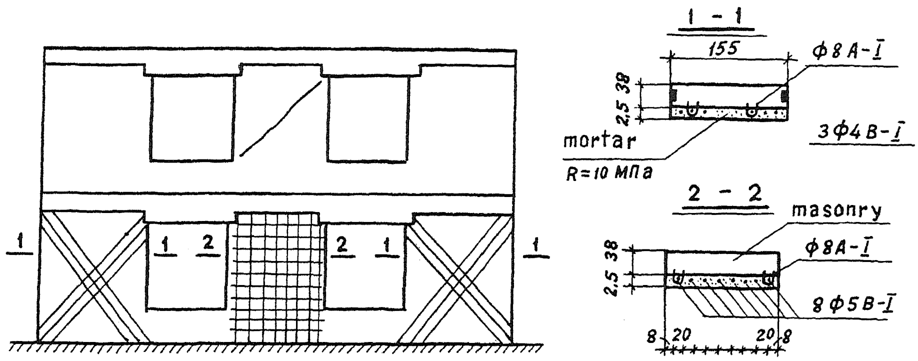

Figure 2. Scheme of damaged masonry strengthening.

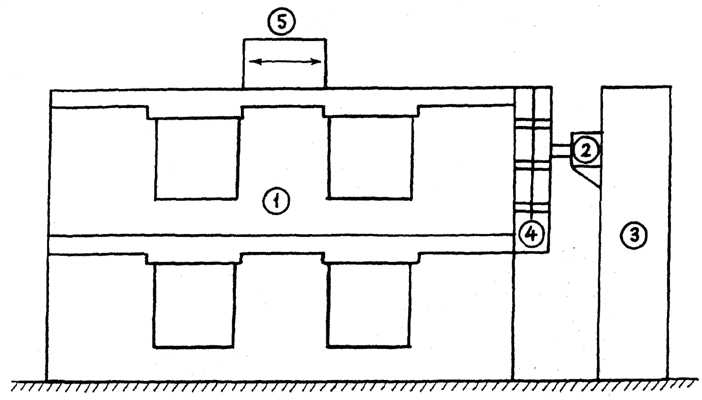

Figure 3. Fragment test set-up: 1 - experimental specimen; 2 - jack; 3 - supporting pier; 4 - steel beam; 5 - vibrator.

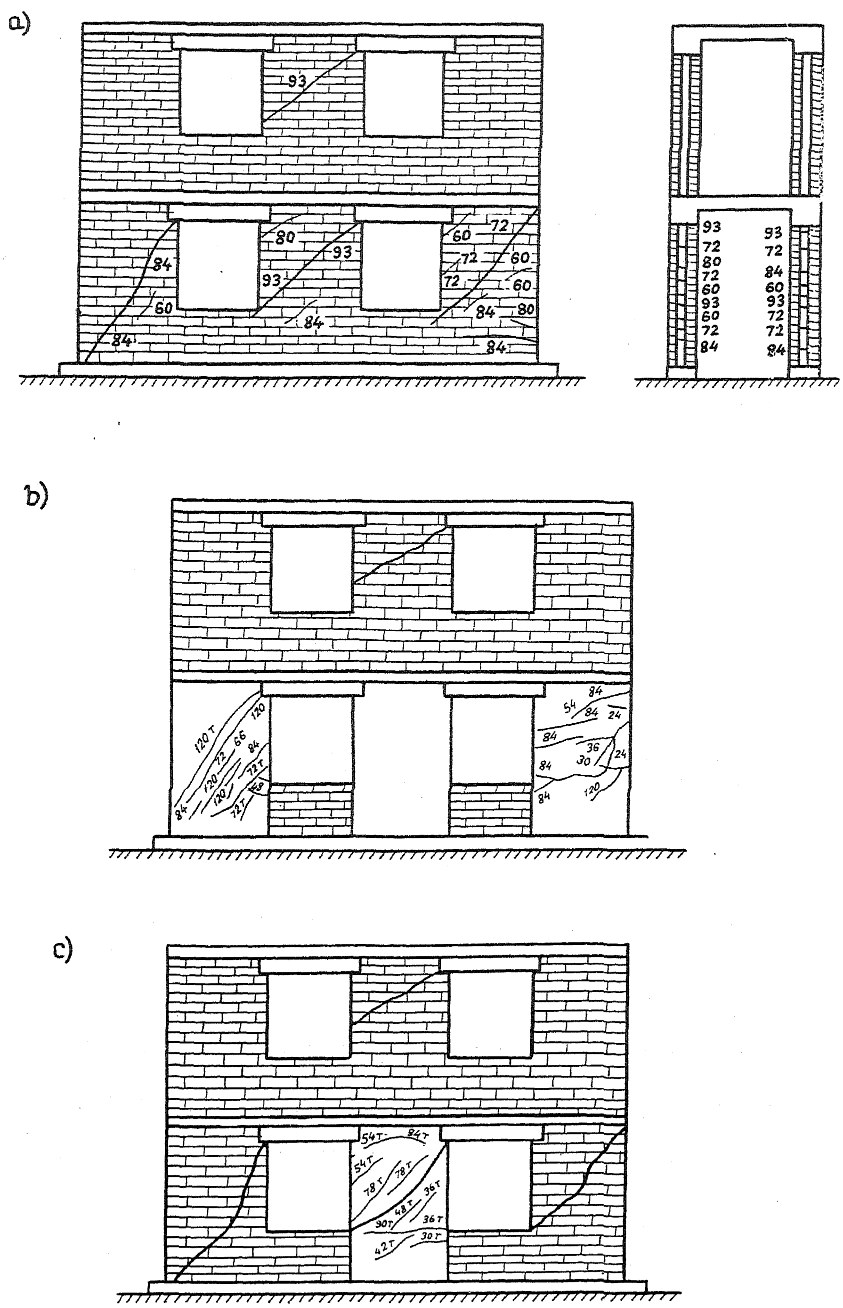

Figure 4. Fragment wall damage scheme: a - unstrengthened masonry; b - ended piers strengthened; c - middle piers strengthened.