Reinforcement of brick partitions of buildings located in seismic areas with composite materials based on carbon fibers

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Abstract. Brick masonry is one of the most commonly used materials for creating internal partitions of buildings, including those located in seismic areas. The codes of a number of countries, including Russia, prescribe design requirements for strengthening partitions with external discrete steel reinforcement. At the same time, this solution is both labor-intensive in the production of works, and increases the seismic load on the partition (increasing the mass of the partition). This article explores the option of replacing the steel external reinforcement of partitions with composite roll materials – grids and tapes on an epoxy basis. The analysis of the strength values obtained in the course of experimental studies is carried out, and the result of calculations of the load-bearing capacity of characteristic partitions of real buildings with and without external reinforcement is given.

1. Introduction
Insufficient load-bearing capacity of curtain structures, such as partitions, can cause significant damage comparable to the destruction of load-bearing structures. Therefore, it is necessary to pay appropriate attention to the design, including such structures as partitions.
Currently, one of the most widely used materials for the construction of partitions is masonry made of ceramic bricks. Partitions made of masonry are also widely used in the construction of buildings in earthquake-prone areas.
In accordance with the regulations in force in Russia, there are special requirements for the construction of partitions of buildings located in seismic areas:
- partitions must be attached to the supporting columns and walls of the building; it is possible to attach them to the ceiling;
- mandatory attachment to the ceiling of partitions longer than 3.0 m;
- horizontal reinforcement of partitions is performed in horizontal masonry joints with rods with a cross section of 0.2 cm² with a step of 700 mm for buildings located in areas with a seismicity of 7 points, and additional vertical reinforcement for buildings located in areas with a seismicity of 8 and 9 points.
The device of this reinforcement of partitions with the use of steel rod reinforcement significantly increases the complexity of the process of constructing such structures. rods are a time-consuming process. In addition, to install reinforcing bars in horizontal masonry joints, it is necessary to increase the thickness of such joints to 25-30 mm, which increases the weight of the partition structure and, as a result, local seismic loads.
An alternative solution to ensure the strength of brick partitions is to strengthen them with external reinforcement systems based on composites. A number of authors studied the work of masonry from the plane [1-15]. At the same time, the research mainly considered the conditions of a biaxial stress state under the combined action of longitudinal and transverse loads. These studies have established the possibility of using composite materials not only based on carbon fibers, but also based on glass fibers for strengthening masonry (comparable results were obtained for a certain thickness of masonry). However, the use of carbon fiber-based composites is recommended as the main material.

In general, the use of composite materials based on carbon fibers is possible in the following combinations:
- external reinforcement device along the plane of the wall/partition made of carbon mesh with a matrix of polymer-cement mortar (in this case, the masonry reinforcement occurs in two directions: horizontal and vertical);
- device for horizontal reinforcement of the wall/partition plane from unidirectional tapes;
- device for horizontal and vertical reinforcement of the wall/partition plane made of carbon unidirectional tapes.

At the same time, when developing solutions to ensure the strength of these partitions, taking into account the use of external reinforcement systems based on composite materials, the method of selecting a section "equivalent" to the structural requirements of standards for earthquake-resistant construction is often used. In fact, this leads to the determination of the cross-sectional area of the composite from equation (1).

\[ R_s A_s = R_f A_f \]  

Where \( R_s \) is the calculated resistance of steel reinforcement;
\( A_s \) – cross-sectional area of steel reinforcement (according to current standards 0.2 cm²)
\( R_f \) – calculated strength of the composite;
\( A_f \) – cross-sectional area of the composite.

In this case, an ambiguous approach is to determine the calculated strength of the composite – it is necessary to take into account not only the strength characteristics of the reinforcement material, but also the adhesion strength of the reinforcement material and the wall/partition structure. On average (when determining the calculated strength of the composite through the reliability coefficients and operating conditions), the equivalent value of the composite (for \( R_s = 0.2 \) cm²) can be obtained as \( A_f = 0.039 \) cm². This design area corresponds to a tape of composite material with a density of 230 g/m² and a width of 50 mm. However, this method of calculating the cross-section of reinforcement elements does not take into account the most important features of the operation of such elements under the action of loads perpendicular to the wall/partition plane. These features include the ability of the composite fabric to perceive significant tensile forces that occur under the local action of a seismic load from the wall plane. It should be noted that masonry made of small-piece materials has an extremely low load-bearing capacity when the specified load is applied from the wall plane, which leads to the need to use additional reinforcement elements that have the required load-bearing capacity. Tapes and webs made of composite materials can be used as reinforcement elements.

2. Efforts in the partition wall

Russian codes allow two options for fixing partitions:
- only for vertical structures;
- to vertical structures and overlap.

These anchors correspond to two schemes of bending moments:
In general, seismic loads on the partition are represented by inertial forces evenly distributed over the surface of the partition. In this case, it is advisable to consider only the action of forces from the plane.

Taking into account the negative impact of the mass of the structure on the resulting force from seismic impact, it is logical to reduce the maximum own weight of the partition. In this regard, the most appropriate solutions are for the construction of external reinforcement systems based on composite materials. In this case, the mass of the reinforcement structure is minimal.

Based on the analysis of the work of the partition structure, as well as previously performed field tests on seismic stands [16-21], the most appropriate and justified are the following schemes for strengthening brick partitions (Fig. 2).

**Figure 1.** Diagram of deformation of partitions under different conditions of fixing.

a) – fixing only to vertical structures, b) fixing to vertical structures and overlap.
In order to reasonably apply external reinforcement to strengthen existing brickwork partitions of buildings located on sites with a seismicity of more than 7 points or higher, tests were carried out on masonry samples. Based on the results, generalized recommendations for calculating masonry from the plane were developed.

3. Experimental studies
In General, the bent partition structure was considered (Fig. 3)
In fact, we consider the case of a wall bending out of a plane. At the same time, vertical loads (the partition's own weight) can be ignored. The design scheme of the partition is shown in Fig. 4.

In this case, the operation of only stretched fibers of external reinforcement is considered. Tests corresponding to this scheme were carried out on prototypes measuring 245x120x450 mm. A General view of the tests is shown in Fig. 5.
As a result of the tests, the values of the maximum load-bearing capacity were obtained. These values were compared with the calculated load-bearing capacity calculated using the [22-25] method:

\[ M_{ult} = R \cdot b \cdot \xi \cdot h^2 \cdot (1 - 0.5 \cdot \xi) \]  

(2)

where \( R \) strength of masonry in compression, determined directly during the test the masonry or accept the tables of applicable regulatory documents; \( h \) – height of the cross section of flexible stone design; \( b \) – cross section width of flexible stone structures; \( \xi \) – the relative height of the compressed zone of the bending stone of the structure. We consider the anchoring of the reinforcement elements secured.

The relative height of the compressed zone \( \xi \) is determined by the formula:

\[ \xi = \frac{R_f \cdot A_f}{R \cdot b \cdot h} \]  

(3)

The results of the research are presented in table 1.

| №  | The description of the sample | M experimental, kN*m | M calculated, kN*m | Error, % |
|----|--------------------------------|----------------------|-------------------|---------|
| 1  | Reference                      | 0,41                 | 0,829             | 80,07   |
| 2  | Carbon mesh reinforcement      | 26068,5              | 1,48              | 43,24   |
| 3  |                                | 2,38                 | 1,93              | 18,73   |
| 4  |                                | 2,50                 | 1,65              | 34,08   |
| 5  |                                | 2,59                 | 2,05              | 20,91   |

At the same time, it is necessary to note the features of deformation and destruction of samples. Samples without reinforcement show minimal deformations and break down brittle, almost instantly. Amplified samples show pronounced deformations from the wall plane and continue to perceive the load after the temporary resistance is reached. The graph of sample deformation is shown in Fig. 6.

![Stress-strain diagram of samples](image)

Figure 6. Stress-strain diagram of samples

The obtained values of the limiting moments were compared with the limit value of the seismic force for different lengths of partitions. As a reference object, a brick building was chosen with the location of the partition in question at the level of the 2nd floor. The calculation results are shown in table 2.
### Table 2. The results of calculation load capacity

| №  | Seismic rating of the construction site | Length, horizontal, m | $\text{M}_{\text{seismic}}$, kN*m | Mult without amplification, kN*m | Mult with amplification, kN*m | Load capacity utilization factor |
|----|----------------------------------------|------------------------|----------------------------------|---------------------------------|----------------------------|---------------------------------|
| 1. |                                        | 3                      | 0.8 437                          |                                 | 0.14                         |                                 |
| 2. |                                        | 4                      | 1.5 000                          |                                 | 0.25                         |                                 |
| 3. |                                        | 5                      | 2.3 437                          |                                 | 0.39                         |                                 |
| 4. |                                        | 6                      | 3.3 750                          | 0.3 360                         | 5.9 904                      | 0.56                            |
| 5. |                                        | 3                      | 1.6 875                          |                                 | 0.28                         |                                 |
| 6. |                                        | 4                      | 3.0 000                          |                                 | 0.50                         |                                 |
| 7. |                                        | 5                      | 4.6 875                          |                                 | 0.78                         |                                 |
| 8. |                                        | 6                      | 6.7 500                          |                                 | 1.12                         |                                 |
| 9. |                                        | 3                      | 3.3 750                          |                                 | 0.56                         |                                 |
| 10.|                                        | 4                      | 6.0 000                          |                                 | 1.00                         |                                 |
| 11.|                                        | 5                      | 9.3 750                          |                                 | 1.56                         |                                 |
| 12.|                                        | 6                      | 13.5 000                         |                                 | 2.25                         |                                 |

### 4. Conclusions

Based on the analysis of the results obtained, the following conclusions can be drawn from the results of the work:

1. In General, partitions without the measures recommended by the standards (surface reinforcement) are not able to accept local loads during seismic impacts.
2. The option of strengthening the designed and existing partitions with external reinforcement based on composite fibers is a reliable solution, a direct analog of strengthening partitions with discrete steel reinforcement.
3. Based on the results of the research, General principles for calculating brick partitions reinforced with external reinforcement based on composite fibers have been developed and justified, which allow determining the load-bearing capacity of the structure with a sufficient level of reliability.

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