DESIGN OF MASONRY BUILDINGS IN SEISMIC REGIONS OF REPUBLIC OF MOLDOVA

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ABSTRACT :

Republic of Moldova is located in a seismic area with the seismicity between 6 and 9 degrees on MSK scale. The epicenter of the earthquakes is in the Carpathian Mountains, in the Romanian region of Vrancea.

During USSR the specialists from the Moldovan Design Institutes were using Soviet construction codes for design of masonry buildings, such as SNiP II-22-81 «Stone Constructions and Reinforced Stone Constructions" and SNiP II-7-81 «Seismic Building Code».

The buildings and edifices that were designed and built at that time according to the above mentioned codes were hit by the Carpathian earthquakes from 1977, 1986 and 1990 without sustaining any serious degradations.

Currently, the design of the stonework buildings is based on Moldovan codes NCM F.03.02-2005 "Design of masonry structural wall buildings". These codes were elaborated by Moldovan scientists who conducted various experimental and theoretical studies.

Based on these fundamental studies, the Moldovan antiseismic engineers developed new constructive solutions aimed to increase the height of stonework walls buildings to up to 9 stories. Moldova is the only former soviet country that designs and builds stonework buildings with such a height in seismic regions.

This report reveals the design requirements for the foundations (footing), the walls and the seismic belts of masonry for buildings with up to 9 stories located in Moldovan seismic areas. These regions have a seismicity range between 6 and 9 degrees on MSK scale. The author believes that these requirements could be successfully applied in other seismic regions in Europe.

KEYWORDS: Masonry, structure, design, frame, anti-seismic belt.

Based on the structure of the walls, the masonry buildings designed in the Republic of Moldova are classified as follows:

a) <u>buildings with stone masonry walls.</u> In such buildings, the masonry of the walls is not armed. In this case the following requirements are to be observed (Table 1):

b) <u>buildings with armed masonry</u>. All the splices of the structural walls in such buildings are reinforced with horizontal armature nets.

The walls between the voids and typically the blind walls as well are reinforced according to the calculations with horizontal armature placed in the mortar of the joints.

When calculated for earthquake intensity of 7 degrees and over, the resistance of the masonry walls can be increased by inserting intermediate elements made from all-cast concrete steel. The armature of the vertical concrete steel insertions must be anchored to the anti-seismic belts.

Table 1

Parameters of the construction element	Maximum dimensions (**m**) at the calculated earthquake intensity, **degrees**			
	6	**7**	**8**	**9**
1.Width of the void walls:				
• in masonry buildings;	0.87	-	-	-
• in armed masonry buildings;	0.80	0.99	-	-
• in buildings with masonry frame structure.	0.60	0.79	1.19	1.59
2. Width of the void walls at most:				
• in masonry buildings;	2.40	-	-	-
• in armed masonry buildings;	2.20	2.00	-	-
• in buildings with masonry frame structure.	3.80	3.40	3.00	2.00
3. Ratio between the width of the walls and the width of the void, at least:				
• in buildings with masonry and armed masonry;	0.36	0.49	-	-
• in buildings with masonry frame structure.	0.15	0.23	0.39	0.66
4. Flat prominences of the armed masonry walls, reinforced with concrete steel, at most:	3.00	2.00	-	-
5. Balcony console, at most	2.00	1.75	1.50	1.25
6. Cornice console, at most:				
• masonry made;	0.30	0.20	-	-
• concrete steel elements, tied to against- earthquake belts (crossbeams);	0.50	0.40	0.30	0.25
• wood made, daubed on metallic net.	0.60	0.50	0.40	0.30
7. The distance in **m** between the axes of the transverse walls or frames that replace them, verified by calculation, in the buildings with masonry and armed masonry, at most:	10.0	8.00	-	-
8. Individual height of the floors	5.40	4.50	3.50	3.00

c) **Buildings in frames filled with masonry.** At all the joints of the structural walls all-cast concrete steel columns will be made, using the masonry as casing. The columns form a spatial frame with carrying capacity filling, together with the all-cast concrete steel belts at each level, made as the masonry goes on.

The height of the buildings/sections must not exceed the values indicated in table 2.

Table 2

Building Type	Height: **m** (number of stories) at the earthquake intensity, **degrees**			
	6	**7**	**8**	**9**
1. In frames filled with masonry	39(12)	33(10)	23(7)	17(5)
2. Steel masonry, with walls:				
• made of burnt brick	17(5)	7(2)	-	-
• other materials	13(4)	4(1)	-	-
3. Stone	10(3)	-	-	-

Foundations

The type of foundation is determined based on the conditions of the land, the constructive scheme in the drawing and the calculated seismicity of the building.. The foundations can be made of raw stone or raw

concrete (Figure 1), all-cast concrete and concrete steel, as well as built-up elements or all-cast prefabs from big concrete blocks. (Figure 2)

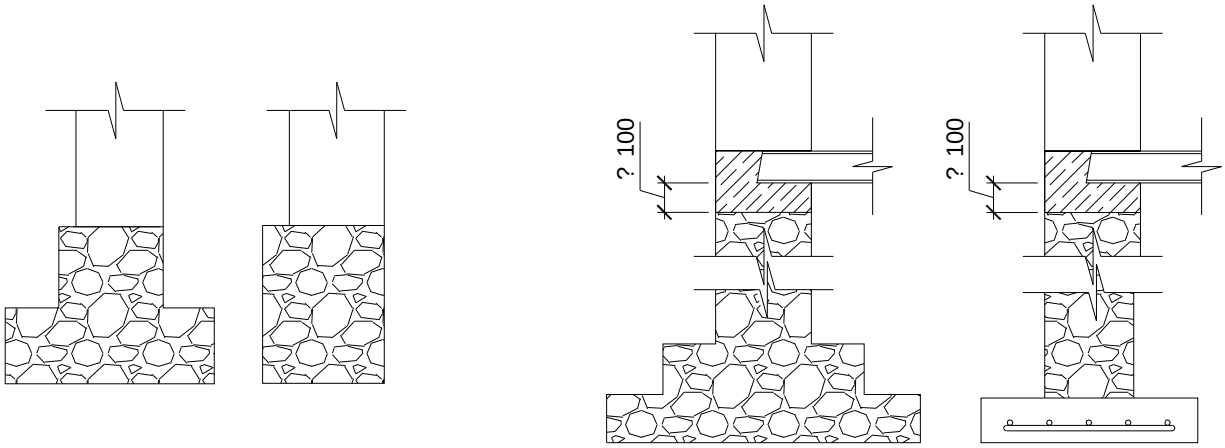

Figure 1. Raw stone and raw concrete foundations for buildings with low number stories.

The foundations made of prefab or all-cast prefab from big concrete blocks can be designed in three ways: without all-cast concrete steel belts (A), with belts at one level (B), with belts at one or more levels (C) (Figure 2)

The belts and the steel joints will be built continuously along the entire foundation of the perimeter walls and interior walls. The steel joints will be built from cement mortar, mark 100, with the thickness of minimum 40 mm, and having longitude armature with 10 mm width, AIII class and 2, 3, and 4 bars at the calculated earthquake intensity of 6, 7, and 8 degrees.

The areas for using different foundations will be determined according to table 3.

Table 3

Foundation type	Use areas
A	Masonry buildings with a height of up to 3 stories, armored masonry buildings with up to 2 stories and earthquake intensity of 6 and 7 degrees. Buildings in frames filled with masonry with a maximum height of 3 stories, at the earthquake intensity of 7.
B	Armored masonry buildings with a height of up to 5 stories, earthquake intensity of 6 degrees. Buildings in frames filled with masonry with a height of 7, 5 and 3 stories, at the earthquake intensity of 6, 7, and 8.
C	Armored masonry buildings with a height 12, 10. 7 and 5 stories, calculated earthquake intensity of 6, 7, 8, and 9 degrees. In all cases of unfavorable foundation land conditions.

In the buildings in frames filled with masonry, the pillars of the frames must join with the foundation belts.

The belts will be armored with at least 4 bars of 10, 12 and 14 mm width, made of class AIII steel for the assumed earthquake intensity of 6...7, 8 and 9 degrees. The cross bars Ø6AI mm will inserted into an interval of 20 cm.

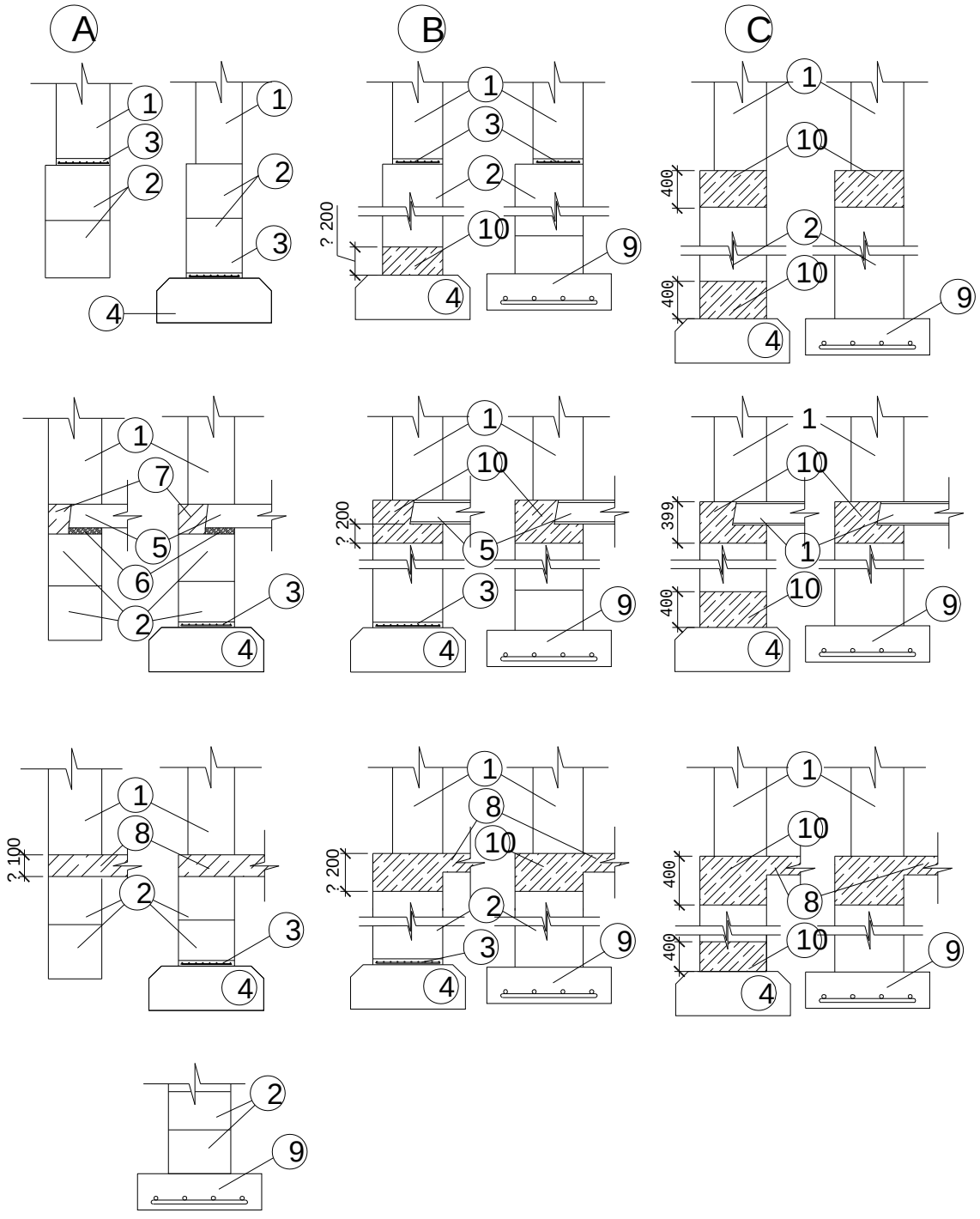

Figure 2. Foundations made of prefab concrete blocks.

1 - building's wall; 2 - foundation blocks; 3 - armored joint; 4 - prefab pillow made of concrete steel; 5 - prefab ceiling; 6 - mortar joint; 7 - all-cast connection belt; 8 - all-cast ceiling; 9 - all-cast pillow of concrete steel; 10 - all-cast or prefab all-cast belt (lineal frame).

THE WALLS

The walls of the masonry buildings are divided in structural walls, which have a thickness of at least 19 mm (without coating), and partition walls. The structural walls are bearing walls, self-bearing walls and non-bearing walls.

The non-bearing walls take over only the own load within the limits of one story of the building, (for example, the filling of a frame cell in a frame structured building).

The self-bearing walls take over only the load of the wall on all its height. The bearing walls take over the load of the wall together with the load of the ceilings, roof, etc.

The thickness of the interior and exterior bearing walls is calculated considering the resistance and the stability.

The structural walls include full walls (without voids between the walls on the *L* perpendicular direction) as well as lame empty walls ($\lambda_p = \frac{l_p}{h_p} \geq 1$) and narrow walls ($\lambda_p < 1$; l_p, h_p - length and height of the empty wall). The value must satisfy the requirements from point 1, table 4.

When designing buildings with up to 5 stories and with longitude bearing walls it is recommended to have at least 3 such walls when calculated intensity is 7. In the case of the buildings with masonry walls it is recommended to use the same structures and the same materials of the structural walls within the limits of the same floor. It is permitted to use the combination of the masonry with concrete steel prefab ventilation ducts (having the same resistance as the replaced masonry object), as well as the concrete steel elements for reinforcing the walls. In buildings with more than 5 stories it is allowed to build the walls at lower floors from materials that are more resistant than the ones used at upper floors, the empty and the void walls should have constant height and the number of the voids should be decreased in the walls at the corners.

In buildings with more than 4 floors and with the calculated intensity of 6 degrees and in all buildings with calculated intensity of 7 or more, it is prohibited to build discontinuous structural walls without building replacing frames from concrete steel, as well as the fracture of the walls' axis that are not reinforced with elements inserted in the concrete steel. It is also prohibited to build "suspended" pillars and structural walls (which do not reach the foundation) and bay windows.
It is forbidden to establish smoke and ventilation ducts that reduce the section of the structural walls (Figure 3).

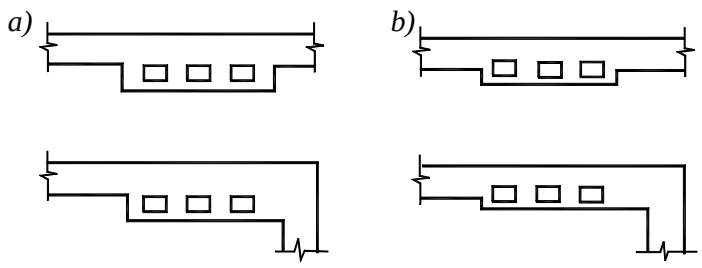

Figure 3 Smoke and ventilation ducts arrangement: indication (a) and contraindication (b)

In case of unfavorable land conditions and in all buildings with calculated intensity of 7, the joints of the brick structural walls and small blocks will be reinforced with armature nets having the transverse area on one direction of at least 1 cm^2, length – 1.50 m, height - 60 cm.

On a length of at least 80 cm on both sides of the joint, the floor belts will be made of all-cast concrete steel.

In buildings with armored masonry with at list 3 stories high, it is recommended to build structural walls of big blocks with the help of concrete steel belts on every floor and. supplementary horizontal all-cast insertions, having longitude armature 4 Ø 10 AIII and transverse of Ø 6 AI. 20 cm pitch.

The bearing perimeter walls of the frame buildings (with at list one floor) that rest on continuous foundation and continuous girder, must have sliding connections with the frames. The pitch of the connections must not exceed 6 m length and 1.2 m height.

The self-bearing walls will be built from masonry and anti-seismic belts. The pitch of the belts on the height of the building will not exceed 3.6, 2.8 and 2 m at calculated intensity of 6, 7 and 8...9 degrees.

The belts must be continuous along the entire length of the self-bearing walls. In case of voids, they must joint with concrete steel jamb of the voids. The belts must be present at the level of all the ceilings, as well as the roof of the building.

The belts built from all-cast concrete and from all-cast prefab should be at least 20 cm high and their width must equal the width of the wall. They should be armored with 4 Ø 10 AIII armature and 20 cm pitch Ø 6 AI transverse.

For the continuous structural walls (without voids) made from brick or blocks, the ratio $\theta = \frac{H}{h}$ (H - height of the floor; h - wall's thickness) at a free wall length of $l \le 2{,}5H$ must not exceed the values presented in table 4.

Table 4

Mortar mark	θ ratio of the masonry group		
	I	II	III
>50	25	22	-
25	22	20	17
10	20	17	15
4	-	15	14

For a free length of the walls $2H \ge l \ge H$ (H - is the height of the floor) the following condition must be observed:

$$H + l \le 3K_c\theta \cdot h \qquad (1)$$

Kc – correction coefficient determined according to table 5.

The values **An** (net area) and **Ab** (gross area) from table 3 are determined on the horizontal section of wall.

For the partition walls unfixed in the superior section, the value of the θ ratio must be 30% smaller than the one established above.

The dimensions of the elements of the partition walls and the distances between them will be established by calculation and will satisfy the requirements of table 4.

Table 5

	Characteristic of the wall	**Kc**, coefficient
1.	Main non-bearing walls with a thickness at least 19 cm	1,2
2.	Partition full walls at least 19 cm thick	1,8
3.	Structural walls with voids	$\sqrt{A_n / A_b}$
4.	Partition walls with voids	0,9
5	Structural and partition walls with a free length between transverse stick watts or columns of 2,5 – 3,5 H	0,9
6.	Structural and partition walls at 1 > 3,5 H	0,8

The parts of the walls and the pillars that go beyond the level of the roof with more than 40 cm, must be reinforced with vertical insertions of all-cast concrete steel anchored in the belt against earthquake (the superior girder of the masonry frames).

The pitch of the insertions will not exceed 2m and the dimensions of the section have to ensure their correct concreting.
The bearing capacity of the masonry walls must be increased by horizontal armature nets.

The nets will be placed in the horizontal joints at least 40 cm high along the height of the masonry. It is recommended to increase the armature in the center of the empty walls by 20% in case of 6...7 degrees calculated intensity and by 40% in case of 8...9 degrees calculated intensity.

In some cases, it is allowed to arrange empty walls with a smaller width, with the condition to reinforce the narrow sides with vertical all-cast concrete steel, tied to the anti-seismic belts. The dimensions of the sections of these elements will be determined by calculation and must ensure their correct concreting.

The bigger voids must have all-cast concrete steel frames whose parameters will be determined by calculation and building conditions. The width of the empty walls at the corner must be considered 25 cm bigger than the values indicated in table 4. The prominences of the walls in the design of the buildings with masonry frames are unlimited on the condition of including frame elements.

When designing buildings with masonry frames it is necessary to have on each floor, on the main axis, at least 15% of the cells with masonry filling and these cells must be symmetrically positioned toward the main axis of the building. Within the limits of a frame cell, it is allowed to have at most two voids in the filling.

For the buildings with masonry frames (Figure 4, 5 and 6), it is not necessary to have a construction connection between the masonry and the elements of the frames with the help of armature whiskers. It is recommended to build the vertical surfaces of the walls, used as casings for the pillars of the frames, with a cogged profile.

ANTI-SEISMIC BELTS

In buildings of masonry and armored masonry, the belts will be built on all the structural walls, at the level of all the ceilings between the floors and the roof.

The belts are made of all-cast concrete steel or prefab concrete, all-cast with continuous armature. The all-cast prefab belts must be composed so that, when built, at least 60% of the surface of the transverse section of the wall will be in contact with the concrete steel. The belts having bearing portions for the ceilings will be mounted along the whole width of the wall. In the exterior walls that are over 400 mm thick, the width of the belt must be at least 400 mm.

The height of the belt should be at list 200 mm in one level buildings and at list 400 mm in multilevel buildings.

It is not allowed the design of prefab elements of big length for belts which cover more than one void in the wall.

The belts will be built from at least A15 class concrete and they will be armored according to the calculation. In addition, the longitude armoring will include at least 4 bars of 12. 14. 16 width of class AIII steel when calculated intensity is 6...7, 8 and 9 degrees. The transverse armoring will be made of Ø 6 A-I bars, with a pitch of maximum 20 cm.

The belts at the top level must be tied with masonry underneath by vertical whiskers with 10 mm diameter ($\leq$40 cm pitch). It is recommended to have the whiskers all-cast by inserting all-cast concrete of at least A10 class.

In buildings with calculated intensity of 6...7 degrees and having all-cast concrete steel ceilings, inserted along the contour of the wall in all its thickness, it is allowed to disregard the arrangement of the anti-seismic belts at the level of these ceilings..

Figure 4. Frame building with filling from sawn lime-stone blocks.

Figure 5. Frame building with filling from sawn lime-stone blocks.

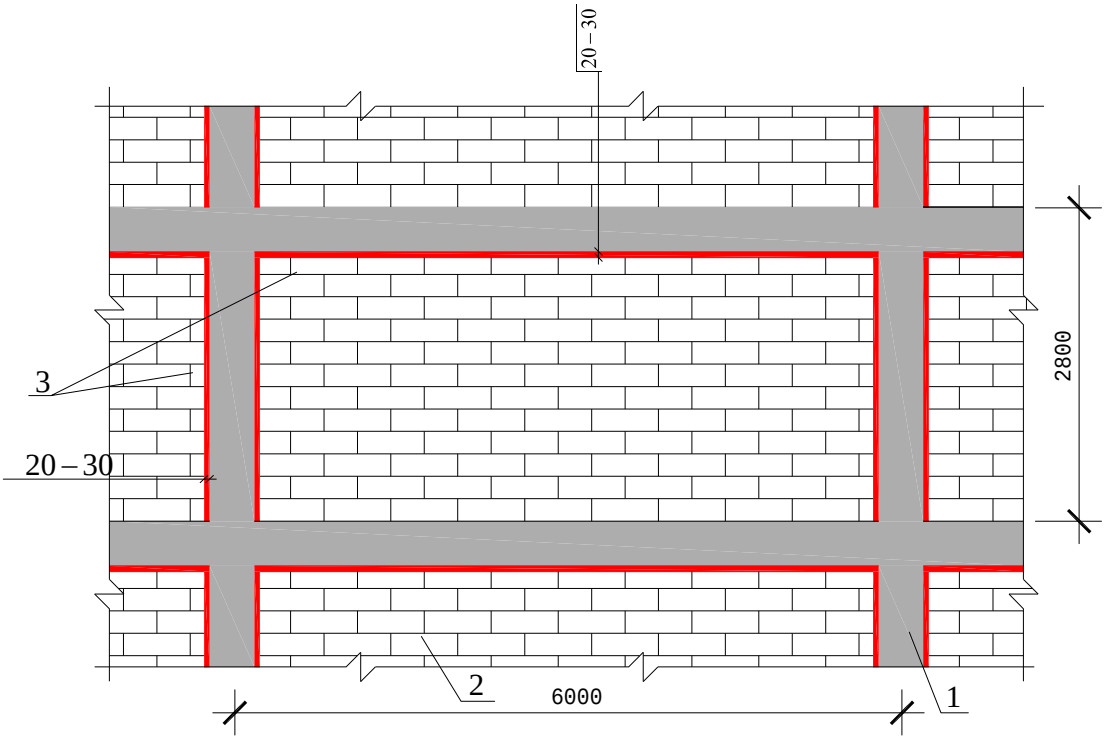

Figure 6. Fragment of frame building with filling from sawn lime-stone blocks.
1 - reinforced concrete frame; 2 - masonry from sawn lime-stone blocks (390x188x188 mm)