IOP Conf. Series: Materials Science and Engineering **775** (2020) 012146 doi:10.1088/1757-899X/775/1/012146

Study of non-formwork hollow-core slabs with support zone restraint in brick walls

A A Prokopovich, V V Repetto and A N Aleshin

Samara State Technical University, 194, Molodogvardeyskaya st., Samara, 443001, Russia

E-mail: Prokopovich@inbox.ru

Abstract. The purpose of the research is to develop a method for calculating the crack formation in the support zones of hollow core slabs manufactured by the non-formwork concreting technology, clamped into brick walls. The testing results of six samples were obtained by a longitudinal cut. On the basis of the experimental data and finite-element modeling using the software complex Lira SAPR-2016 a method for calculating cracks formation in the support slab zones pitched in masonry has been developed and presented. The developed method of calculation allows taking into account the ductility of the slab joints with bricklaying, the length of the sealing of the support zones, the value of the average compressive stresses in the masonry, as well as spans, stiffness characteristics of slabs and load application schemes. The recommendations concerning support points reduction at designing support slab assemblies clamped into a brick wall are provided.

1. Introduction

A widespread introduction in Russian plants of precast concrete technology of casting without formwork for the manufacture of hollow-core prestressed concrete floor slabs and coatings has led to their wide use in construction, instead of the traditional hollow-core slabs.

Slabs made by non-formwork casting technology have the longitudinal reinforcement, unlike traditional hollow-core slabs manufactured by aggregate-flow or conveyor method which have additional non-stressed reinforcement in the form of horizontal grids and vertical frames, meeting current Russian normative documents. This leads to certain difficulties in the design of non-formwork hollow-core slabs and their floors. In particular, this is associated with the calculation and design of slab support units, pinched into brick walls.

The purpose of the study is to create a method of calculating the non-formwork hollow-core slabs for the normal cracks formation in the restraint places in brick walls and, on its basis, to develop constructive solutions to support moments reduction. The realization of this goal includes experimental and theoretical studies.

The article provides experimental studies were conducted on the experimental samples, obtained as a result of the longitudinal cuts of two identical slabs with the thickness of 220 mm with round holes with the width of 1195 mm and the length of 7160 m.

Theoretical studies, including the analysis of the experimental results, the development of a calculation method for the normal cracks formation in the places of slab restraint in brick walls, and recommendations to reduce the support moments in their design on the basis of the software complex Lira SAPR.

2. Experimental study

All slabs manufactured by the technology of non-formwork casting are designed, as a rule, with the upper prestressed reinforcement in such a way that the formation of normal cracks on their upper surface at all stages of operation is excluded, provided that they are freely supported.

However, in cases of restraint of the slab support zones in walls (brick, block, panel, etc.), as shown in [1, 2], there are support moments that lead to the formation of normal cracks on the upper surface of slab in places of their restraint into the walls even in the presence of the upper prestressed reinforcement.

To exclude the possibility of normal cracks formation at operational (normative) loads on the slabs, clamped into the walls, in [1] the formula for determining the maximum normative load on the slab, at which no cracks on the supports will be formed, is proposed. To assess the pliability of the clamping units, it is proposed to use experimentally found numerical values of the "coefficient of the degree of clamping" equal to the ratio of the experimental reference moment in the restraint in the crack formation to the theoretical support moment determined at the same load on the slab under the assumption of rigid restraint on the support. Such a purely experimental approach to the problem of preventing cracks in the near slab restraint into the walls has a number of significant drawbacks. The main of them is the lack of the possibility of correct use of experimental numerical values of the "coefficient of the degree of restraint" obtained as a result of the test of specific slabs (span, thickness and width of the section, the shape of voids, concrete class), for slabs with other characteristics, pinched into the brickwork strength and deformability which are different from those used in the experiments.

Experimental studies were carried out to study the nature of the work of non-formwork hollow core slabs without the upper prestressed reinforcement, clamped in masonry and obtain experimental data quantitatively characterizing the behavior of the slabs in the process of changing the test load from zero to destructive.

2.1. Samples and test bench

In total, six samples were tested in the form of fragments sawn from 7.2 m long slabs reinforced with steel cores Ø12 mm of class K1500. The cross-section of the initial slabs is shown in figure 1.

The schematic diagram of the tests and the general view of the test bench with the sample №1 are shown in figures 2 and 3, respectively.

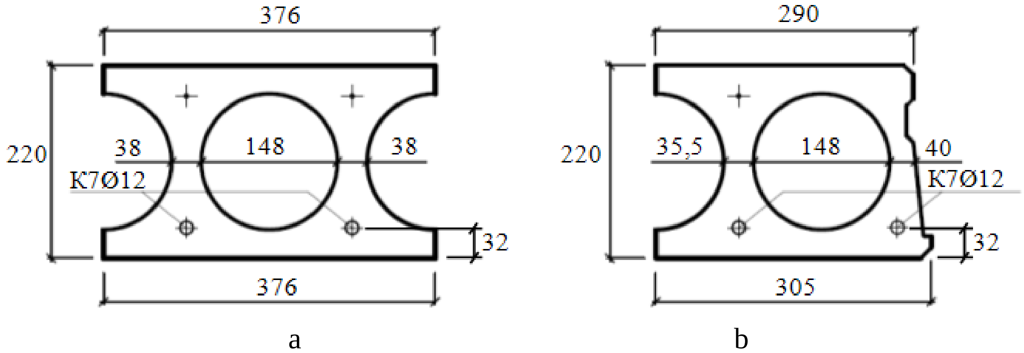

Figure 1. Averaged cross-section dimensions and reinforcement of samples. a – samples №№ 1÷4; b-samples №№ 4 and 5.

The stand consists of two rigid metal space frames, the designs of which are adopted to provide the rigidity of the sample closing in the masonry and the application possibility.

The load on the samples. The frames are fixed in the design position by concrete blocks installed on them. One end of the samples was closed with a brick column section 38*38 cm and a height of 1.5 m, the other one had a hinged support. The column was loaded from above with the help of a hydraulic Jack, vertical force N, simulating the weight of the overlying floors.

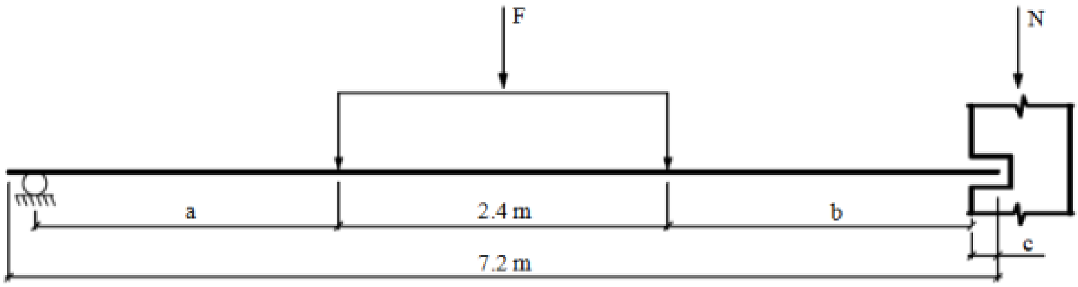

Figure 2. Concept scheme of testing samples

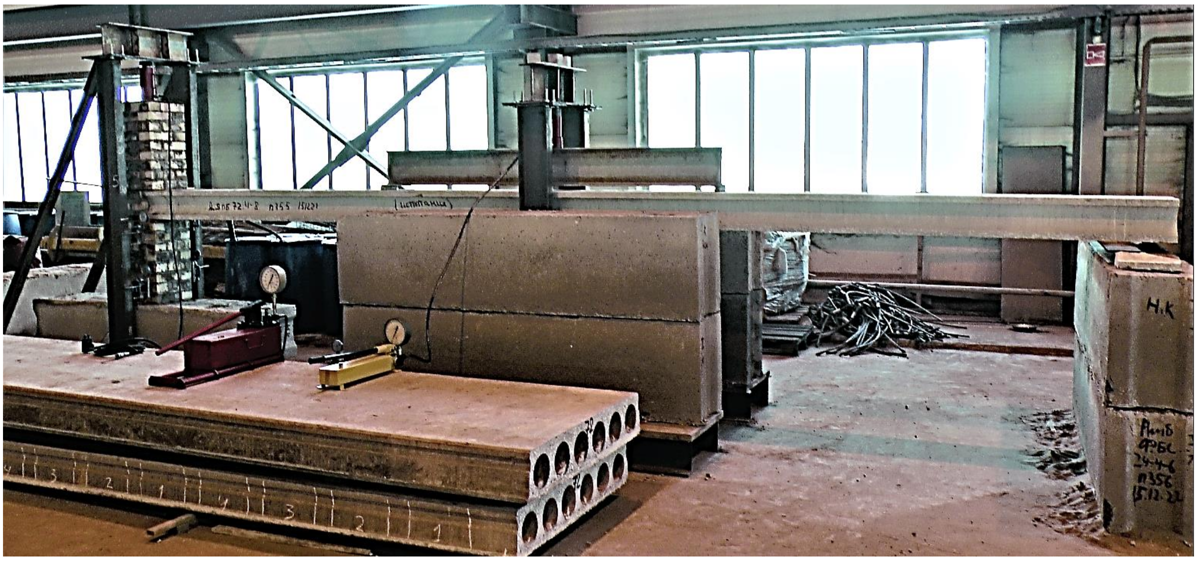

Figure 3. General view of the test bench with sample number 1.

Parameters of test schemes (a, b, c, N) for each sample, strength and deformation characteristics of concrete samples and masonry are given in table 1.

Table 1. Test schemes parameters, strength and deformation characteristics of samples and masonry

Sample number	a, cm	b, cm	c, cm	N, kN	R_m, MPa	R_{btm}, MPa	E_{b1}, MPa	R_{1m}, MPa	R_{2m}, MPa	E_0, MPa
1	213	229	11	107	41.1	29.9	28849	12.3	10.3	4120
2	235	228	12	300	41.1	29.9	28849	12.3	10.3	4120
3	235	228	12	300	41.1	29.9	28849	12.3	10.3	4120
4	235	227	13	300	41.1	29.9	28849	12.3	10.3	4120
5	235	226.5	9.8	300	41.1	29.9	28849	12.3	10.3	4120
6	211	230.5	9.5	300	41.1	29.9	28849	12.3	10.3	4120

Designations accepted in table 1: R_m - average cubic strength of concrete samples; R_{btm} - average strength of concrete samples on axial tension; E_{b1}= 0.85 E_b –the module of concrete deformations; E_b - the initial modulus of elasticity of concrete; R_{1m} - the average strength of the brick compression; R_{2m} - the average strength of the solution compression; E_0 - the initial modulus of elasticity of the masonry.

The compressive strength of concrete samples was determined by the method of separation with chipping and corresponded to class B32, and the axial tensile strength of concrete was calculated by the Feret formula depending on the average cubic strength. The initial modulus of elasticity of concrete of E_b samples is adopted in accordance with [3] for concrete of B32 class. The actual strength characteristics of the masonry are determined by the results of testing of brick samples and mortar fragments of masonry, and its initial modulus of elasticity by direct loading during the test samples.

2.2. Methods and samples test results

The load F on the samples was applied in steps of 2÷3,5 kN with exposure at each stage for 10 minutes. The force N was applied prior to loading the specimens and remained constant until the end of the test.

Prior to testing the sample bending, caused by the compression force of concrete pre-stressed reinforcement was measured. During the test cracks and the width of exposure were recorded. Deflection at specimen midspan and supports settlement were measured with the help of flexometer with a scale division of 0.01 mm

The sample №1 test. The bending of the sample before the test was 14 mm. The first cracks in the sample in the clamping zone appeared at a load F= 21.2 kH. (Figure 4A). The deflection of the sample in the middle of the span at the same time was 10.7 mm. Then the crack increased in its length and width. Normal and inclined cracks in the sample (in the middle part of the span) were found at a load of F= 26.8 kN . The test was terminated at load F=41 kN. The view of the clamping zone at maximum load is shown in figure 4b.

a b

Figure 4. Cracks in the restraint zone of sample №.1. a - at load F=22.8 kN (crack opening width up to 0.2 mm); b - at load F=41 kN (crack opening up to 7.0 mm).

The sample №2 test. The bending of the sample before the test was 15 mm. a Crack in the clamping zone appeared under load F=19.2 kN (figure 5a). The deflection of the sample in the middle of the span at the same time was 10.0 mm. Then the crack increased in its length and width. Normal cracks (in the middle part of the span) were found at a load F=23.3 kN, and inclined at a load on the sample F=26.8 kN (figure 6). The test was terminated at load F=41 kN. The type of specimen in the restraint zone at maximum load is shown in figure 5b.

The sample №3 test. The bending of the sample before the test was 14 mm. the Behavior of the sample during the test is similar to sample No. 2. A crack in the restraint zone appeared at a load of 19.4 kN. The deflection of the sample in the middle of the span was 10.1 mm. Normal cracks (in the middle part of the span) were found at a load F=23.3 kN, and inclined at a load on the sample F=26.9

IOP Conf. Series: Materials Science and Engineering **775** (2020) 012146 doi:10.1088/1757-899X/775/1/012146

kN. The test was terminated at load F=38.8 kN. The type of specimen in the clamping zone at maximum load is shown in figure 7a, after complete unloading in figure 7b.

The sample №4 test. Bending of the sample before the test was 15 mm. Peculiarity of the

a b

Figure 5. Cracks in the restraint zone of sample №2. a - at load F=21 kN (crack opening width up to 0.3 mm); b - at load F=41 kN (crack opening up to 9.7 mm)

Figure 6. Normal and inclined cracks in sample №2 at load F=26.9 kN.

a b

Figure 7. Cracks in the restraint zone of sample №3. a - at load F=19,4 kN (crack opening width up to 0.5 mm); b - at load F=38.8 kN (crack opening up to 10.5 mm)4

test sample was the presence in the support area of a soft pad of polystyrene with a thickness of 10 mm width of 50 mm to increase the pliability of the interface of the slab with the wall (figure 8a). The distance from the laying plane from the side of the span to the soft gasket is 90 mm, i.e. the effective width of the gasket on the upper surface of the sample was 40 mm. In this case, in the sample, in the restraint zone, a crack was not formed until the end of the test. However, when the sample was loaded F=18.2 kN, a vertical crack appeared at the entire height in the upper part of the masonry fragment with a width of up to 1.5 mm. With increasing load on the sample crack opening width in the masonry increased and at maximum load F=41 kN reached 6 mm (figure 8b). In this case, a vertical crack with an opening of up to 1 mm and a horizontal gap between the mortar seam and the lower face of the sample appeared in the masonry under the lower face of the sample (figure 8c). Normal (in the middle part of the span) and inclined cracks in the sample were found at a load F=27.4 kN. The test was terminated at load F=41 kN.

a b c

Figure 8. Support area of sample № 4. a – before loading; b - at a load of 41 kN (over the sample); c- at a load of 41 kN (under the sample); 1 - soft gasket.

<u>The sample №5 test.</u> The bending of the sample before the test was 15 mm. In the support zone of the sample there was a soft gasket, as in the sample №4, of polystyrene 10 mm thick, 50 mm wide, the distance from the masonry plane from the span to the soft gasket 83 mm, i.e. the effective width of the gasket on the upper surface of the sample was 18 mm. the crack in the restraint zone appeared at a load F=14.6 kN. The deflection of the sample in the middle of the span at the same time was 10.2 mm. Then the crack increased in its length and width. Normal cracks (in the middle part of the span) were found at a load F=16.9 kN, and inclined at a load on the sample F=23.5 kN. The test was terminated at load F=41 kN. The view of the sample with normal and inclined cracks at maximum load is shown in figure 9.

<u>The sample №6 test.</u> The bending of the sample before the test was 14 mm. the behavior of the sample during the test is similar to sample № 5. A crack in the restraint zone appeared under load F=15 kN (figure 10a). The deflection of the sample in the middle of the span was 10 mm. Normal cracks (in the middle part of the span) were found at a load F=18.2 kN, and inclined at a load on the sample F=23.5 kN. The test was terminated at load F=41 kN. The types of specimen in the restraint zone at maximum loads are shown in figure 10b. The view of the sample with normal and inclined cracks at maximum load is shown in figure 9.

A characteristic type of support zones of samples after completion of their tests and removal from the stand is shown in figure 12. It can be seen that the support zones are in satisfactory condition. There are no signs of concrete destruction and core slipping.

Figure 9. Normal and inclined cracks in sample №. 5 at load F=41 kN.

a b

Figure 10. Cracks in the restraint zone of sample № 6. a - at load F=15 kN (crack opening width up to 0.2 mm); b - at load F=41 kN (crack opening width up to 12 mm).

Figure 11. Normal and inclined cracks in sample № 6 at load F=41 kN.

The results of sample tests necessary for determination of compliance of their connection with brickwork are given in table 2.

Table 2. Sample test results

	Sample number					
	1	2	3	4	5	6
F_{crc}, kN	21.2	19.2	19.4	-	14.6	15.0
f_{crc}, mm	10.7	10.0	10.1	-	10.0	10.0

IOP Conf. Series: Materials Science and Engineering **775** (2020) 012146 doi:10.1088/1757-899X/775/1/012146

The designations accepted in table 2: F_{crc} – load on a sample at the time of normal crack formation near the restraint in a brickwork; f_{crc} – a deflection in the middle sample span at load of F_{crc}.

Figure 12. State of the supporting parts of the samples dismantled after testing.
1 - normal crack near ground; 2 - cores.

3. Theoretical research

3.1. Analysis of sample test results

The test results mentioned above showed that normal cracks near the support zones restraint of the test specimens in the brickwork were formed in all samples except sample № 4. This indicates the presence of support moments in the closing zone of samples in brickwork, leading, under certain conditions, to the normal cracks formation near the restraint, which agrees with the data of other studies [1, 2] slabs of non-formwork casting. In this regard, the work under load of both samples and non-formwork hollow core slabs can be divided into two stages: before the formation of a normal crack near the support zone restraint and after. This article analyzes in detail the nature of the samples only at the first stage, as the Russian design standards do not allow cracks in the areas of support slabs. After the crack formation in the restraint zone, an almost ideal joint is formed and the behavior of the samples at this stage is well described by the traditional design scheme in the form of a freely supported beam, which is confirmed by the nature of the formation and development of cracks and deflections with further increase in the load. In this case, the transverse force arising in the sample along the face of the wall is perceived only by the zone of compressed concrete of insignificant height under the normal crack and the cores of the longitudinal working reinforcement, which are peculiar anchors embedded in the concrete of the supporting part of the sample clamped into the brickwork, which is fully complies with the conclusions given in the work [2]. The reliability of the cut cores as an anchor is confirmed by the state of the supporting parts of the samples (figure 12) taken from the test bench after the tests completion.

In addition, the main factors affecting the flexibility of the support nodes of the samples were experimentally established. These include: the average stress in the masonry; the presence of soft pads in the support area; the length of the platforms support. The same factors are noted in the works [1, 2,] but so far in the domestic practice there is no theoretically justified method of calculation, which allows taking into account these factors in a wide range of their values in the design of support units of non-formwork hollow core slabs, clamped into brick walls.

This technique is developed by the authors on the basis of finite-element modeling using PC Lira SAPR and test results of samples in the assumption that the flexibility of the nodes is determined mainly by the deformation characteristics of mortar joints that transmit the load on the masonry. The development of the technique included several stages: determination of the flexibility of the support

IOP Conf. Series: Materials Science and Engineering **775** (2020) 012146 doi:10.1088/1757-899X/775/1/012146

zones of the samples clamped into the masonry; construction of a finite-element model for numerical analysis of the test results of the samples and the determination of the deformation module of the mortar seam in the support zone; development of finite-element models for the calculation of slabs on the formation of cracks in the restraint areas in brick walls.

3.2. Determination of pliability of clamping units of samples in masonry.

In order to develop a method for the calculation of cracking in the bearing areas of the non-formwork hollow core slabs, clamped in masonry, the basic feature of samples pliability was the angle of rotation β of the support cross section coinciding with the surface of the brickwork from the side of the spans. The test results allow the calculation (using computer simulation) to correctly determine for each sample only one specific value of the angle β_{crc}, which corresponds to the moment of formation of a crack in the closing. To do this, the values of F_{crc}, f_{crc}, and the moment of crack formation in the support section of the M_{crc} should be known. The first two values are given in table 2, and the value of M_{crc} can be obtained by calculation using the strength characteristics of concrete given in table 1. The method described in [4] was used to calculate the moment of cracks formation in the support section. This technique allows determining the moments of the cracks formation in the zones stretched from the efforts of the preliminary compression, for cross sections of any shape on the basis of planar finite-element models in nonlinear statement using the Lira SAPR. It uses full threelinear diagram of the concrete state [3] and specified for the extended concrete. The moments of crack formation calculated by this method have the following values: for samples with numbers 1÷4 M_{crc}= 10.8 kN*m; for samples with numbers 5 and 6 M_{crc}= 7.75 kN*m.

To calculate the angles of β_{crc} rod finite-element models with hinged support nodes were used. Their sections and parameters of rod finite elements were set with the help of the section designer PC Lira SAPR in accordance with figure 1 and table 1 (figure 13).

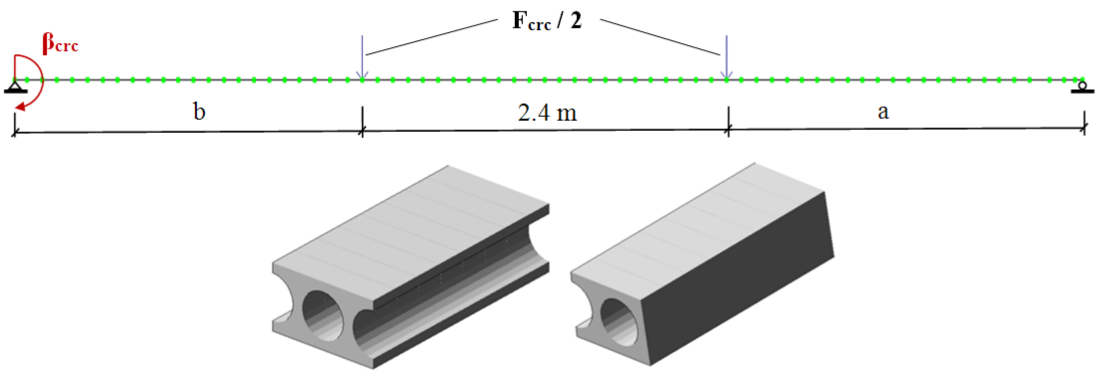

Figure 13. Road finite element model and 3D images of finite elements, modeling samples.

The calculations were performed by the method of successive approximations for each sample in the following order: a load in the form of a forced rotation angle β was applied to the node adjacent to the masonry, the vertical load F_{crc} was applied to the model in accordance with figure 2 and table 1; the finite-element model was calculated and the obtained values of the reference moment and deflection in the middle of the span were compared to the values of M_{crc} and f_{crc} ; in case of their discrepancy, the value β was corrected, the finite-element model was calculated again and the results were compared; the described process was repeated to the maximum possible coincidence of the compared values, and the value of the rotation angle was taken as the desired value of β_{crc}.

The calculated values of rotation angles for all samples are given in table 3.

Table 3. Rotation angle β_{crc} of support cross-sections of experimental samples.

	Sample number					
	1	2	3	4	5	6
β_{crc}, rad	0.00362	0.00322	0.00324	-	0.00330	0.00349

3.3. Finite-element model for determining the deformation modulus of a mortar joint.

The finite-element model for determining the deformation modulus of the mortar joint is shown in figure 14.

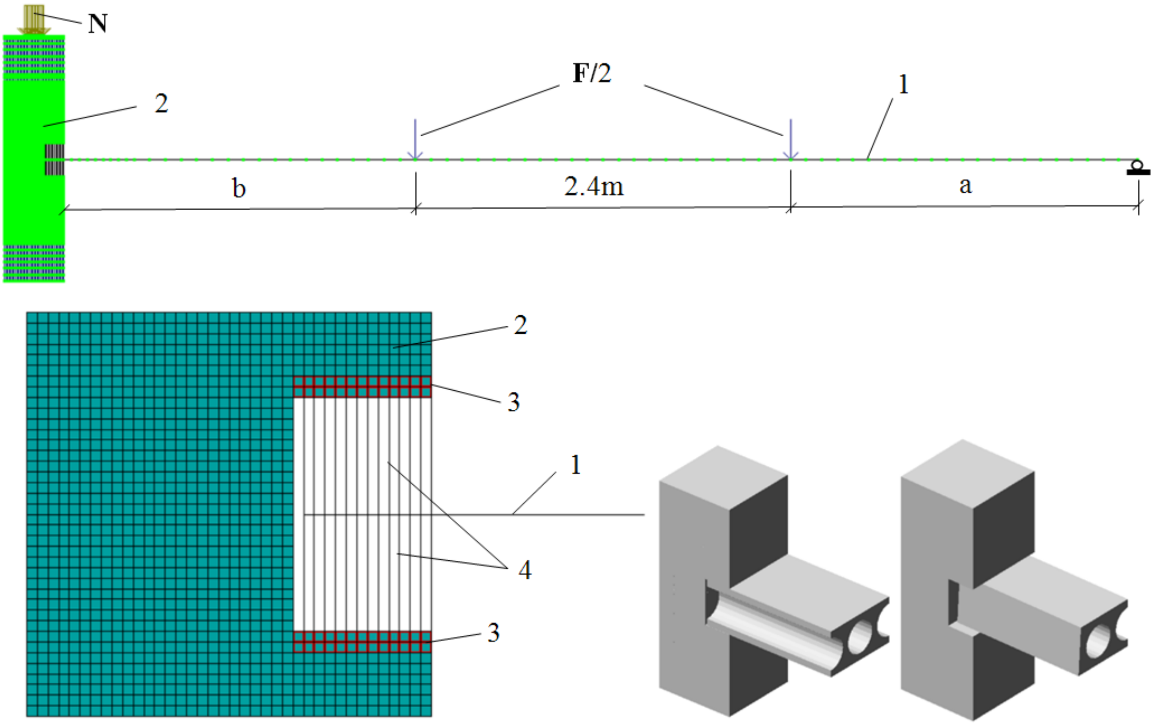

Figure 14. Finite-element model for determining the modulus of deformation, of the mortar joints, its fragment at the level of sample closing and 3D image of the support units. 1 – sample; 2 – masonry; 3 – mortar joints; 4 – rods of high rigidity.

Masonry and mortar joints were modeled by shell finite elements with thickness equal to the thickness of the brick column, into which the samples were closed. The modulus of deformation of the masonry was taken according to table 1. Experimental images were simulated with truss elements, shown in figure 13, and their elasticity modulus was made according to table 1. Core elements of great stiffness ensure interaction between the finite elements, joints, modeling samples with the mortar joints. The force N generated by the uniformly distributed load corresponded to the load applied to the masonry during the test of the specimens. The loads F in the calculation of each sample were applied in accordance with figure 2 and table 2.

The deformation modulus of mortar seam was determined by the method of successive approximations by calculating the above finite element model on the load of the F_{crc} corresponding to the moment of crack formation in the restraint zone of each sample. The desired value of mortar seam deformation modulus was taken to be as that when the reference moment in the closing from the load of the F_{crc} taken, according to table 2, became equal to the corresponding value of M_{crc} given in subsection 3.2.

It is necessary to take into account that the calculations performed with the model shown in figure 14 should be carried out by the method of successive approximations, with the removal at each step of those rigidity rods in which tensile forces arise. Thus the interaction of the sample with mortar seams and masonry is additionally simulated.

The deformation modulus of the solution seam defined in this way with the characteristics of the solution given in table 1 is assumed to be 153.8 MPa. The calculations results of the model shown in figure 14 (angles of rotation β^*_{crc} at the time of cracks formation in the clamping and corresponding deflections f^*_{crc}, in the middle of the span), performed with this value of the deformation modulus of mortar seam and their comparison with the experimental values taken from tables 2 and 3, are given in table 4.

Table 4. Calculation results of finite element models for samples.

	Sample number					
	1	2	3	4	5	6
β^*_{crc} рад	0.00396	0.00312	0.00316	0.00296	0.00314	0.00337
f^*_{crc}, mm	11.4	10.3	9.8	9.8	10.8	9.2
β_{crc}, рад	0.00362	0.00322	0.00324	0.00320	0.00330	0.00349
f_{crc}, mm	10.7	10.0	10.1	9.7	10.0	10.0
$\beta^*_{crc}/\beta_{crc}$	1.094	0.969	0.975	0.925	0.951	0.966
f^*_{crc}/f_{crc}	1.065	1.030	0.970	1.010	1.080	0.920

Designations accepted in the table 4: β^*_{crc}, f^*_{crc} – theoretical values of the angles of rotation and deflections in the middle of the span obtained from the calculations of the model shown in the figure 14; β_{crc} , f_{crc} – experimental values of the angles of rotation and deflections in the middle of the span, taken from tables 2 and 3;

The calculations results presented in table 4 indicate a fairly good agreement of the experimental results with the results of numerical calculations based on the plate-rod system "sample – masonry" presented in figure 14. From this it follows that the finite-element models of such a structure can be used to calculate the slab plates on the formation of normal cracks in the places of their restraint into brick walls.

3.4. The calculation of the non-formwork slabs for the formation of normal cracks in restraint places into brick walls.

Calculation of slab plates on formation of normal cracks in places of their clamping is carried out from the condition:

$$M_{crc} \geq M \quad , \tag{1}$$

Where M_{crc} - the moment of formation of a normal crack in the slab in the clamping;

M - support bending moment in the slab in the clamping of the standard load (excluding own weight)

The moment of cracks formation for the upper faces of the slabs of non-formwork molding is determined in accordance with c [5] by the formula:

$$M_{crc} = \gamma_p \left(R_{bt,ser} \gamma W\right), \tag{2}$$

IOP Conf. Series: Materials Science and Engineering **775** (2020) 012146 doi:10.1088/1757-899X/775/1/012146

Where γ_p - coefficient taking into account the impact of the efforts of the preliminary compression of the concrete at the time of the formation of normal cracks in the area of cross-section stretched from the action of the efforts of the preliminary compression P;
$R_{bt,ser}$ – the calculated resistance of concrete to axial tension, taken, depending on the class of concrete slab, according to [3];
γ - coefficient taking into account inelastic properties of concrete in bending elements without prestressing of reinforcement;
W - elastic resistance moment of the cross section to the extreme tensile fiber of the slab.

The support bending moment M in the slabs, clamped on both sides into brick walls, is determined by numerical calculations of finite-element models, each of which, in specific cases, is a plate-rod system "slab - masonry" similar in structure to the model in figure 14. The difference between them is only in the design solutions of the support slabs on specific walls and in the scheme of application of loads on the masonry and slabs.

Figure 15 shows the finite-element model of the plate-rod system "slab - masonry" with axisymmetric variant of the support slabs on the walls.

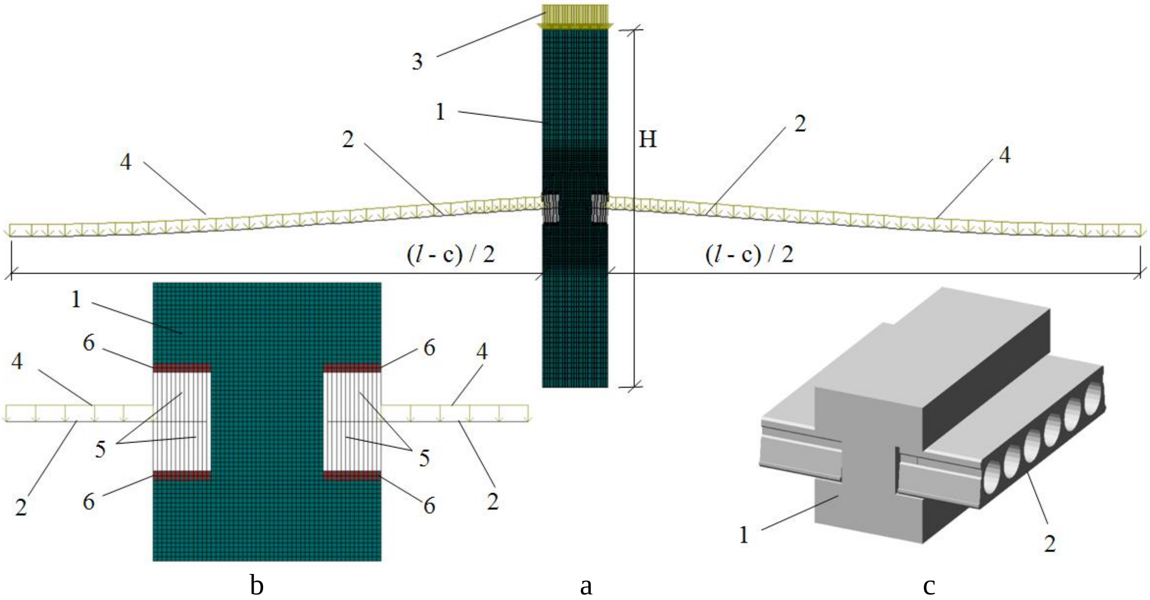

Figure 15. Axisymmetric finite-element models of the system "slab - masonry" (a), fragment of the finite-element model at the level of slab closing in the masonry (b) and 3D image of the support unit (c). H – floor height; l - slab length; c - depth of embedment of the supporting zones in the wall; 1 – masonry; 2 – slab; 3 – load providing the required compression of masonry; 4 - standard load on the slab; 5 – rods of high rigidity; 6 - mortar joints.

The calculation of slabs in the formation of normal cracks restraint in the brickwork, using a finite-element model in figure 15, is the following:

1. The slab parameters required to calculate the moment of normal cracks formation on the verge stretched from the efforts of the preliminary compression in the restraint place are defined. The moment of M_{crc} crack formation is found according to the recommendations [4], or by any other conventional methods. It should be taken into account that the accuracy of the definition of M_{crc} largely determines the effectiveness of the proposed method of calculation and engineering decisions taken on its results.

2. A finite-element model of the slab-masonry system is created taking into account the following provisions: the height of the masonry in the model should be equal to the height of the floor of the building for which the slab is intended; the masonry is modeled by shell finite elements (FE) with a

thickness equal to the width of the calculated slab, and their deformative characteristic is assumed to be $0.8E_0$, where E_0 is determined according to [5] depending on the strength of the mortar and brick; slab is simulated by rod FE of general form, and their geometric and deformation ($E_{b1}= E_b$ 0.85) characteristics are taken depending on the type and cross section dimensions of slabs and concrete [3]; high rigidity rods are modeled by FE of general form of square cross-section; the mortar seams in the pinching with a thickness of 20 mm are simulated by shell FE of thickness equal to the width of the slab, and their deformation modulus is taken equal to 153.8 MPa with the solution brand of 10 MPa or below and a 248.4 MPa at solution brand of 20 MPa and higher for the intermediate grades deformation modulus is assumed by linear interpolation [6]; the load on FE slab modeling, linear and should meet the regulatory burden on the stove, without considering its own weight; the load on top of the masonry linear, and its value depends on the specified level of average stress in it.

3. The finite element model calculation of the system "slab – masonry" should be performed by the method of successive approximations. From the first, the forces arising in the high rigidity rods are controlled. The rods that have tensile efforts are removed. The calculation continues until all remaining rods are compressed. The reference moment *M* obtained in this way (figure 16) is compared to the moment M_{crc}, i.e. the condition (1) is checked. If it is performed, there will be no crack in the support area of the slab under operating load. Otherwise, a crack under operational loads will be formed and constructive measures will be required to prevent its occurrence.

Figure 16 shows the calculation result, according to the above procedure, for the slab with a length of 7.2 m and a width of 1.2 m under a design load of 8 kN/m^2. The original data slab and masonry: concrete class B35; γ_p = 1,0; $R_{bt,ser}$= 19.9 MPa; γ = 1,415; W = 7785 cm^3; M_{crc} =22.2 kN*m; the laying of brick stamps on the M125 mortar brand M100; depth of embedment of the supporting zones in the wall – 120 mm.

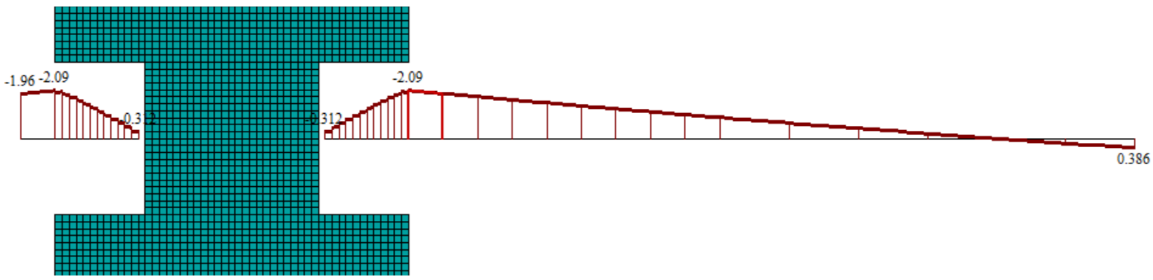

Figure 16. Result of the calculation of the finite element model of the system "slab - masonry".

The reference torque obtained from the calculation (figure 16): M = 20.9 kN*m. Checking the condition (1) gives:

$$M_{crc}=22.2 \text{ kN*m} \geq M = 20.9 \text{ kN*m},$$

i.e. normal cracks in the support zones of the slab are not formed under operating loads.

Otherwise, the simplest and most effective design solution to prevent the cracks formation in the support areas, clamped in masonry, is the installation of soft pads on the ends of the slabs (fig. 8a). The required pads width is determined by the calculation described in the previous (third) paragraph, with the only difference that the upper rigidity rods at the ends of the slabs on the pad width are to be removed before the calculation. The rest of the calculation process does not change.

4. Conclusion

1. In the support areas of the non-formwork slabs clamped into brick walls, there are negative reference points leading under certain conditions to the normal cracks formation from the top slab surfaces close to restraint. After the formation of such cracks, the slabs from statically indeterminate structures turn into practically statically definable, working according to the scheme of freely supported beams, which is confirmed by the samples testing.

IOP Conf. Series: Materials Science and Engineering **775** (2020) 012146 doi:10.1088/1757-899X/775/1/012146

2. In all the samples in the support areas, clamped in the masonry just one normal crack is formed (from the span) and developed with increasing load. When reaching the limit of flow in the armature of the samples (in the middle part of the span), the width of the crack opening near the clamping reached (depending on the specific sample) 7.0÷12.0 mm. It is obvious that the transverse force acting on the verge of restraint was perceived only by the zone of compressed concrete of a small height under the crack and the rods of the longitudinal working reinforcement, which, in this case, act as anchors, embedded into the concrete of the supporting part of the sample, clamped in the brickwork.

3. The support point values in the areas of the slabs in masonry depend upon the pliability of the nodes with the masonry. The samples tests of the main factors affecting the ductility of the nodes of the bearing slabss which are closed up in masonry: the deformation characteristics of the masonry and mortar seams; the length of the sites of the intersection; average stress in the masonry. It was experimentally confirmed that there is a possibility of reducing the support moments by installing soft pads at the ends of the slabs on their upper surface.

4. The method of calculation on normal cracks formation at pinching of non-formwork slabs in brick walls with use of finite-element modeling of systems "slabs -brickwork" on the basis of the program complex Lira SAPR was developed and offered by authors. The proposed method allows taking into account in the calculations all the main factors affecting the ductility of the connection of slabs with masonry, as well as the slab stiffness characteristics, their spans, and loading schemes.

References

[1] Berdichevsky G I, Kramar V G, Arzumanyan K M et al. 1983 Improvement of structural forms, methods of calculation and design of reinforced concrete structures *IX all-Union conference on concrete and reinforced concrete* 43-50

[2] *Research report NO RTE77/02* 2002 *Experimental research on wall-slab connections, Vtt buildingand transport,* Helsinki

[3] *Set of rules* 63.13330.2018 2018 *Concrete and reinforced concrete structures. Main provisions,*

[4] Prokopovich A A, Aleshin A A and Zemlyanskikh S K 2018 Taking into Account the plastic properties of concrete in determining the moment of formation of normal cracks in bending elements with a complex shape of cross sections. *Construction, collection of articles* 145-149,

[5] *Set of rules* 15.13330.2012 2010 *Masonry and reinforced masonry structures*

[6] *Set of rules* 335.1325800.2017 2017 *Large-panel structural systems. Design rules*