Выводы. Таким образом, контроль состояния канализационных сетей не утрачивает своей актуальности, что подтверждается аварийным и предаварийным состоянием значительной части канализационных сетей в городах Украины.

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THE CHOICE OF RATIONAL TYPE AND QUANTITY REINFORCEMENT FOR MULTICAVITY REINFORCED SLABS

1. Introduction

Nowadays Ukraine introduces new technologies in manufacture of pre-stressed floor slabs, including formed at girdleless bench. The nomenclature of articles in sufficiently variegated and embraces a broad range of spans and loads. One of the main problems in design and manufacture of those elements is selection of appropriate type and amount of reinforcement.

In this connection we analyzed engineering solutions existing in world practice and on this basis brought proposals on optimization of slab reinforcement with ropes and high-strength wires Вр1400 (Вр-II).

In development of those proposals and recommendations, our objective was to optimize reinforcement consumption for a given load and to determine the minimum acceptable concrete strength permitting to omit transversal and upper longitudinal reinforcement.

As a result, we proposed slab design with span 2.4...9.0 m, width 1200 mm corresponding to calculated useful uniformly distributed load 8.0 кN / m^2. Slabs are designed as structures free of cracks in normal and oblique sections under operational loads. All slabs have unified thickness 220 mm as well as 6 unified diameter 152 mm round cavities. Beams either on wall brickwork or on girder shelves support slabs. For brickwork support case we studied the degree of slab rigid fixing in the wall to define the probability of cracking in its top area.

Besides, we performed theoretical studies in strength of normal and oblique sections, crack resistance of structures under operational and calculated loads as well as slab deformability under instantaneous and long-term loads. We verified slab top stresses during force transmission from stressed reinforcement to concrete.

All calculations were performed in accordance with provisions of ДБН В.2.6-98:32009 «Бетонные и железобетонные конструкции» [1] и ДСТУ Б В.2.6-156:2010 [2]

As a result, we came to the following conclusions:

-for 2.4…5.4 m span slabs Class C30/35 concrete is advised, for long-span slabs (before 9.0m) – Class C32/40 concrete

-2.4…3.6 m span slabs may be reinforced with high strength wires Bp1400;

-4.2...9.0 span slabs may be reinforced К1400 with cables of appropriate diameters 9 mm, 12mm. 15 mm (table 1).

In order to verify theoretical results we developed a methodology for slab control test. This method is totally harmonized with provisions of EN 1168:2005+A2:2009(E), Annex J [4]. In particular, we determined in advance control loads for bending moment and transverse force strength as well as boundary values of deflection.

2. Stressed strained state modeling

Within the frames of theoretical modeling we also studied definition of slab geometrical parameters (embedding depth) at which support bending moment emerges in slab embedding into small element brickwork.

In this connection we analyzed stressed strained state of slab support area on wall. This is necessary to define the feasibility of reinforcement location in slab top area (double reinforcement). To this end we studied creation of representative calculation procedure for similar structure.

Table 1 - Constructive parameters slabs

Mark of slab	class of concrete	The area of section reinforcement, cm^2		Option of reinforcement
		for the calculation of the strength of	for the calculation of crack resistance	
MRS24-12-8	C30/35	0,434	-	4∅5 Hr-II
MRS 33-12-8		0,848	-	5∅5 Hr -II
MRS 36-12-8 (MRS 36-12-8)		0,99	-	4∅9 К7 (6∅5 Hr -II)
MRS 42-12-8 (MRS 42-12-8)		1,37	-	4∅9 К7 (7∅5 Hr -II)
MRS 48-12-8		1,81	0,55	4∅9 К7
MRS 51-12-8		2,11	0,71	5∅9 К7
MRS 54-12-8		2,31	1,61	5∅9 К7
MRS 60-12-8	C32/40	2,84	2,5	7∅9 К7
MRS 63-12-8		3,24	3,43	7∅9 К7 (5∅12 К7)
MRS 66-12-8		3,59	3,87	5∅12 К7
MRS 72-12-8		4,32	5,43	6∅12 К7
MRS 78-12-8		5,09	7,01	8∅12 К7 (5∅15 К7)
MRS 84-12-8		5,97	8,89	10∅12 К7 (7∅15 К7)
MRS 90-12-8		7,04	10,83	11∅12 К7 (8∅15 К7)

For this purpose and with due consideration of the fact that slab section is weakened by six holes we verified the hypothesis that its section may not be deformed in its own plane. The obtained information served as a basis to accept slab model in the form of beam. Wall embedding was reflected in additional spans with length varied from minimum support site length to its maximum value equal to 1000 mm (Fig. 1)

As a result, we built a calculation model in the form of finite elements, whereas calculation was performed in environment of software package «LIRA» (лиц.№ 8202018) [7, 8] This caused application of universal spatial rod FE-10 type elements. For analysis we selected slab maximum span of 9.0 m Slab support site on wall was admitted as minimum 160 mm and maximum 1000 mm. For rods within wall embedding area support was modeled by assigning an additional characteristic – bed coefficient C1 which also varied from 104 kN/m^3 to 105 kN /m^3. Load on the basic (middle) span was taken as equal to total load (own weight) plus useful load, whereas load on lateral spans was taken as equal to weight of walls and floors of a 16-storey building. In doing this, load on support-adjacent area of slab from above-lying storeys was varied with discrete series: $2{\cdot}10^3$ kN/m, $4{\cdot}10^3$ kN/m и $6{\cdot}10^3$ kN/m Reduced useful load on slab in span was admitted to be 1.44t/m. Physical geometrical characteristics of slab-modeling rod were assigned by numerical values: $EA = 4521{\cdot}10^3$ kN, $EI_y = 26{,}6{\cdot}10^3 kN{\cdot}m^2$ ($A=1507\ cm^2$, $I_y = 88691\ cm^4$)

The results of calculations showed that under specified lengths of support sites up to 15 cm bending moments were values of higher order infinitesimal as compared to span values.

Then, within the frames of theoretical study we additionally estimated the possibility of slab section turn at the place of its embedding into brickwork. To this end we formed support area 3-D model. Modeling and calculation were also performed in environment of software package «LIRA»

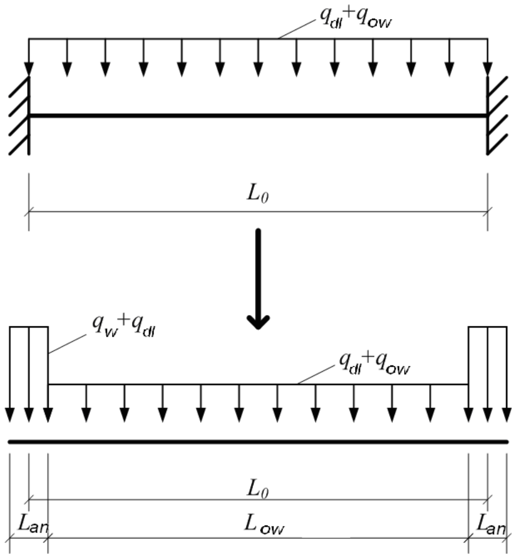


Fig. 1. To the formation of the computational model slab (q_{ow} – own weight load, q_{dl} – dead load, q_w – weight of wall)

The obtained finite-element 3-D model of floor slab support area is shown in Fig 2. The structure is approximated with three-dimensional FE-36 universal spatial eight-node isoparametric finite elements. The dimensions of all voluminous finite elements 2×2×2cm.

At slab edge the force was assigned P=2,5t (0.05 t to each note with finite element step 2 cm) causing at embedding the emergence of bedding moment corresponding to load moment 1.44 t/m (slab useful load plus its own weight). Load on wall from above-lying structures and walls was assigned to be $2{\cdot}10^3$ kN/m^2. For all voluminous elements conforming to the properties of their materials of construction first type deformation modulus and Poisson ratio were determined as $E=25{\cdot}10^5$ kN/m^2, $\nu=0{,}25$ for brickwork; $E=15{\cdot}10^6$ kN/m^2, $\nu=0{,}17$ mortar in joint; $E=3{\cdot}10^7$kN/m^2, $\nu=0{,}17$ slab concrete. Mortar joint was modeled with oblique rods of 2×2cm section, with pivots at connection areas with slab.

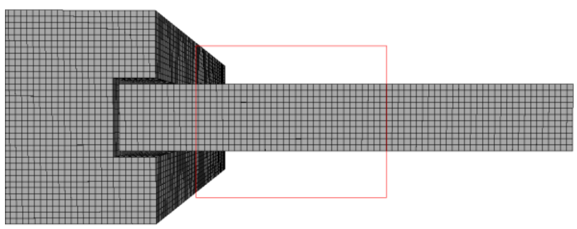


Fig. 2. The finite element 3D-model joint of support floor slabs on the wall

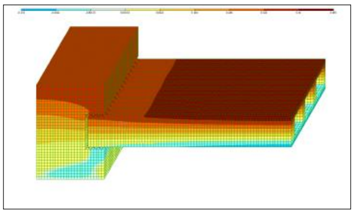
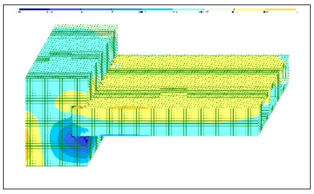
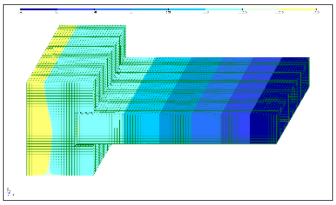
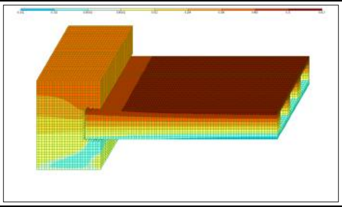
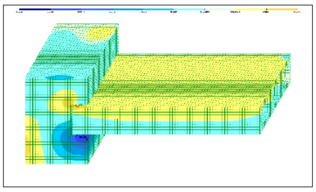
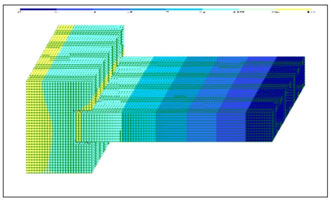
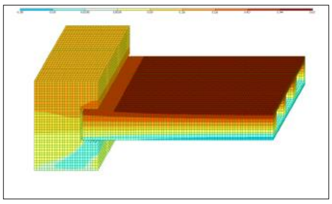
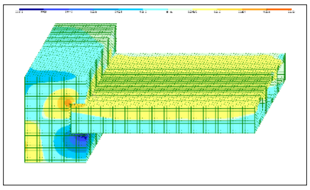
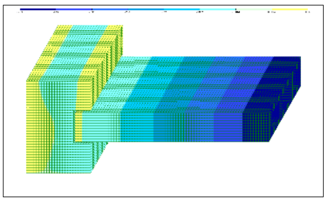
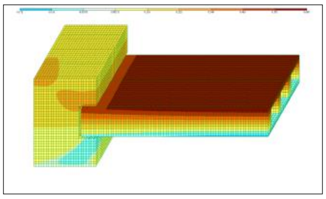
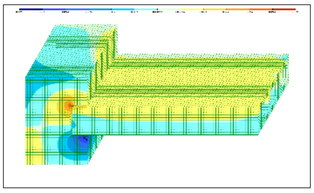
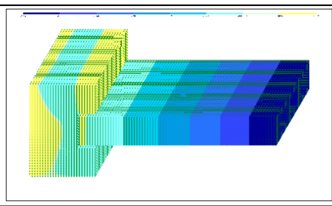
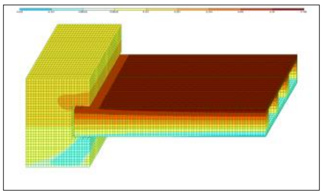
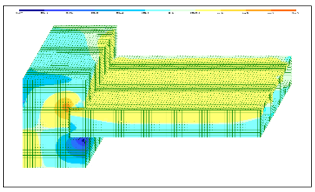
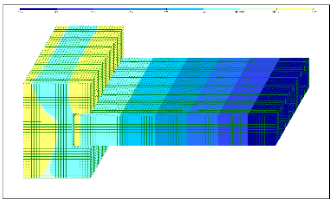
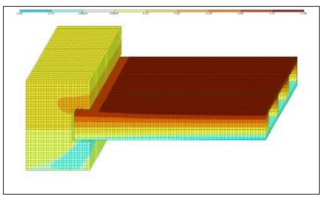
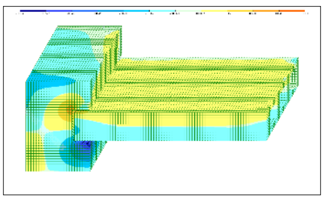
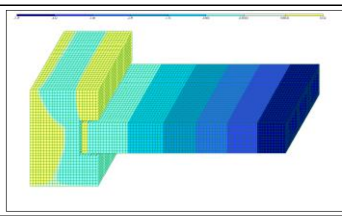
With due consideration of non-linear junction operation, namely, violation of slab and brickwork joint movement, the calculation was performed as iteration under deformed scheme. At each iteration step force sign was determined in rods modeling mortar joint operation, and in case it was positive, i.e. tension in the rod, it was removed. At final end the fact of deviation (turn) in the joint was stated and contact areas between slab and brickwork determined.

Calculation results of slab support area on brick wall are specified in the form of isofields of movements along axes X, Y and Z. The analysis of isofields of movements showed that in the area under study a turn took place at theoretical angle of $1{,}6\times10^{-4}$ rad and, consequently, support bending moment tended to zero. See isofields in Table 2.

3. Experimental verification

The obtained theoretical results passed integral verification by experimental study of natural samples. The number of samples was 2 Slab span was 6,3 m, reinforcement 5∅12K1400

Table 2 – Isofields of displacement in support joint

	Isofields of structure displacement along X axis	Isofields of structure displacement along Y axis	Isofields of structure displacement along Z axis
Initial finite element model start			
First iteration			
second iteration			
thirds iteration			
fourth iteration			
Resultant field			

Experiments were executed under two programs.

Basic program: determination of strain character, crack formation and destruction under concentrated load according to N 1992-1-1:2004+AC:2008, IDT.Еврокод-2 [4] и EN 1168:2005+A2:2009(E), Annex J [5], including comparison of results with theoretical control loads.

Additional program: slab tests of strength, rigidity and crack resistance in accordance with provisions of [2] under uniformly distributed load.

In the course of those tests also the degree of slab embedding in brickwork had to be determined.

3.1 Study of 6.3 m span slab stressed strained state under instantaneous local load

Object of study: 1200mm wide 6280 mm long reinforced slab of 5∅12К1400 Class concrete, without transverse and longtitudinal top reinforcement C32/40.

The slab was tested at test laboratory of reinforced concrete structure department, Kharkov National University of Construction and Architecture. The slab was 28 days old, made of C32/40 Class concrete. Ambient air temperature was 20 °C, humidity 80 %.

Loading system: test was effected by application of concentrated load F at 600 mm distance from support.

The loads was applied with a single Model 100-ton jack brand DW-25 via a rigid transverse beam of channels-iron № 20 ensuring uniform load distribution across slab width. Supports A and B were of roller type: A was hinge fixed, B - hinge movable. Support responses were uniformly distributed across slab width. (Fig. 4)

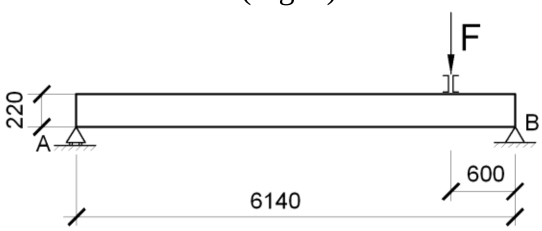


Fig. 4. The scheme of loading slab

Measurement system: Straining parameters were measured with mechanical and electronic instruments. Arrangement of instruments is shown in Fig 5-6.

Here we see I1…I4 - clock-type indicators IW10 with least division 0.01mm; P1…P4 - deflectometers 6ПАО with least division 0.001mm, D1, D2 – indicators IW 10 fixing reinforcement sliding in concrete; numbered instruments 1...8 are inductive pickups IDI-100, connected to SMIT-3 electronic strain measurement system..

Fig. 5. General view of the test

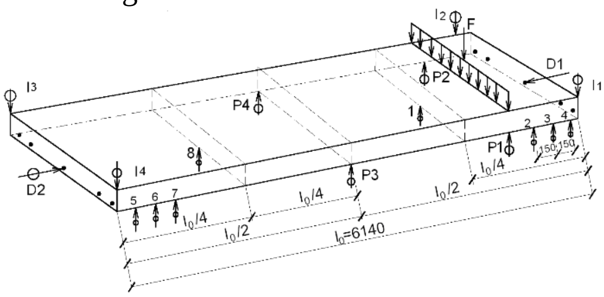


Fig. 6. The plan for the instrumentation

Experiment sequence: Loads were applied in two cycles.

In Cycle 1 load of 75% of calculated breaking load was applied in two stages within time period of 1 min Expected breaking load (calculated control load) was 157 kN.

In Cycle 2 at first stage a load ranging from 0 to 50% of calculated breaking load was applied within 1 min (85 kN); at second stage a load ranging from 0 to 75% (120kN) was applied within 1 min, then the load was consecutively increased at the rate of 15 kN/min up to final breaking.

Conclusion: From test results we can note the following:

-breaking took place at load of F =170 kN;

-breaking took place along inclined section at the angle of approximately 450, simultaneously all across slab width. The inclined crack begins on slab bottom face, at the distance of 200 mm from the support;

-slab deflections f were determined as average values from instrument readings:

-under the applied force F

$$f = [(P1 – I1) + (P2 – I2)] / 2 ;$$

-at slab center

f = [(P3 – I1) + (P4 – I2)]/2

and were 0.26 mm under the applied force F and 0.595 at slab center.

According to instrument readings the support did not sink.

-reinforcement did not slide in concrete during test and was found only on support at the moment of breaking. Reinforcement slide was 1.11 mm.

Actual concrete compressive strength under test was admitted according to provisions of ДБН В.2.6-98:2009 [1] and EN1168:2005+A2:2009(E), Annex J [5],

fc = fck / 0,95 = 32 / 0.95 = 33,7 МПа

as well as average concrete tensile strength,

$$f_{ctm} = 0{,}3\sqrt[3]{f_c^2} = 0{,}3\sqrt[3]{33{,}7^2} = 3{,}13 \text{ МПа;}$$

actual tensile strength was admitted as

$f_{ct} = 0{,}8 f_{ctm} = 0{,}8 \cdot 3{,}13 = 2{,}5$МПа$= 0{,}25$кН/см^2

Testing (control) slab transverse force bearing capacity was determined by formula:

$$V_{Rd,c\,test} = \frac{I_{red} b_w}{S}\sqrt{f_{ct}^2 + \alpha_1 \sigma_{cp} f_{ct}},$$

where $\alpha_1 = 1$; $\sigma_{cp} = P/Ac$; S - static moment of section area above central axis relative to that axis; I_{red} - reduced section moment of inertia; b_w = 26,8 cm - total thickness of all vertical partition between holes and was equal to $V_{Rd,c\,test} = 152 kN$.

Calculated concentrated load applied at the distance of 600 mm from support:

$F_{calc} = V_{Rd,c\,test} / 0{,}902 – V_g$,

where V_g - calculated value of transverse force from equivalent uniformly distributed load (slab own weight) at the distance of 0.6 m from support, equal to 11.8 kN.

Control load was

F_{calc} = 152 / 0,902 – 11,8 = 156,7 kN.

Actual breaking load was F_{test} = 170 kN.

Ratio F_{test}/F_{calc}=170/156,7 = 1,085 > 0,95, i.e. actual bearing capacity, proved to be higher than theoretical value of breaking load, by 8.5 %.

Conclusion: From test results we can note the following:

-slab test according to the provisions of EN1168:2005+A2:2009(E) showed its sufficient strength;

-in the course of test under the loads below calculated boundary values not a single normal or inclined crack was found in the slab, deflections were within calculated values, reinforcement did not slide in concrete;

-safety factor F_{test} / F_{calc} = 1,085 confirms the reliability of slab calculation model.

3.2. **Slab operation study under instantaneous and long-term uniformly distributed load on ДСТУ Б В.2-6-7-95 [3]**.

The slab was tested at test laboratory of Kharkov National Technical University of Construction and Architecture in August-October 2013.

The slab was 28 days old at the beginning of tests.

Concrete of stab is C32/40 class

Ambient air temperature was 20 °C, its humidity 80%

Object of study: 1200mm wide 6280mm long reinforced slab of 5∅12К1400 Class concrete C32/40, without transverse and longtitudinal top reinforcement.

Loading system: Hydraulic loading test was performed [6]. Test stand included a bath disposed on the slab top surface and filled with water in the course of test. (Fig.7)

The bath was made of wood and insulated with waterproof film. Load of bath own weight was 0,5 kN/m^2.

Fig. 7. Test slab hydraulically loading

Bath boards were 1150 mm high to ensure maximum temporary load 11 kN/m^2.

Water was supplied and removed via respective nozzles.

The value of temporary load in the course of test was determined by measurement of water column height. Such loading system was in full conformity with theoretical uniformly distributed load and ensured monitoring of slab stressed strained state at any moment.

The slab under test had both roller pivotally movable support and partial embedding into brickwork (Fig.8).

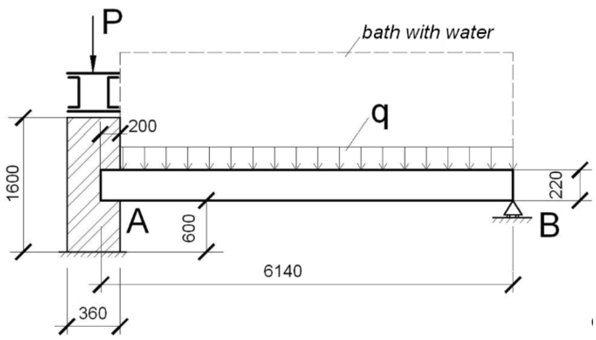


Fig. 8. The scheme of loading slab

To imitate actual load from above-lying storeys brickwork was additionally loaded with a special cross-piece which with the help of a jack and force field ensured a force 800kN, equivalent to pressure on the slab from above-lying 13-storeys of apartment block. The slab was embedded into wall at the depth of 200 mm (Fig.9).

Fig. 9. Entrapment slab on a support

Measurement system: Straining parameters were measured with mechanical and electronic instruments. Arrangement of instruments is shown in Fig 10

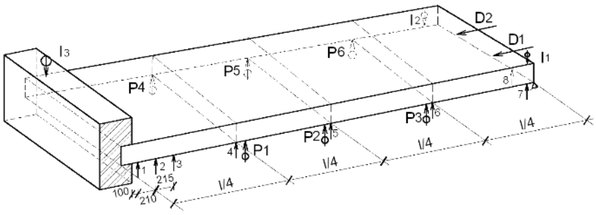


Fig. 10. The plan for the instrumentation

Loads were applied stagewise in increments of 2 kN/m^2 up to the value of calculated temporary load 8.5 kN/m^2, then in increments of 1.0 kN/m^2 up to the value of maximum temporary load. After application the load at every increment was maintained for 10 min.

In the course of test deflections were measured in the middle and at the quarters of span as well as support subsidence. Displacement of reinforcement ends relative to concrete at the edge of support was measured with indicators Д1 and Д2.

Maximum temporary load on the slab (with bath fully filled with water plus own weight of bath) was 10.7 kN/m^2.

Then this load was fixed and maintained to determine slab strain parameters under long-term loading.

Instruments readings were observed within 39 days, water level in the bath being maintained constant.

Due to risk of eventual slab breaking under loads close to boundary calculated values and, as a consequence, depressurization of water-filled loading bath, actual maximum temporary load was 10.7 kN/m^2, which is less than control load for the 1 case of breaking by 4.5% and for the 2 case of actual breaking by 16.4 %/

Actual value of bending moment at slab center was 84.27kNm, or 86% of slab calculated bearing capacity.

Nevertheless, recognizing the fact that all this load was long-term (practically constant), the attained straining parameters were treated as acceptable.

Conclusion: From analysis of the slab test results under instantaneous loading we can note the following:

-slab displacement at its center was 0.259cm;

-slab displacement at quarters of its width were:

-near support A – 0.190cm;

-near support B – 0.194 cm;

-slab turn angle under maximum load were:

-near support A – 1,5 · 10^{-4} rad;

-near support B – 0,71 · 10^{-4} rad;

deviation from theoretical value being 6.7%.

-in the course of slab loading from 0 to 10.7 kN/m^2 any normal or inclined cracks were not observed.

After unloading (removal of bath) all surfaces of the slab were thoroughly observed. No cracks, spalling or other microdestructions were seen. This confirmed the assumption that negative bending moments actually did not take place on the support (in slab embedding into brickwork), so, the supporting may be treated as pivotal. This circumstance was evident in favour of pre-calculation assumptions (Fig. 11).

Fig 11. The upper surface of slab 11 about pinch after the test

Conclusion: From the analysis of slab test results under long-term load we can note the following:

-presence of turn angle under slab straining on support A (within brickwork) and lack of cracks in slab top area justified our idealized modelling of slab supporting in brickwork in the form of pivotal support;

-concrete creep under long-term load is evident during 1.2 days. The value of obtained creep ratio φ (∞,t_0) ~1,3 lies within acceptable range;

-with slab suffering a force from above-lying brickwork equal to 800kN (which is equivalent to above-lying 13-storeys of apartment block) no destruction was found in the concrete, thus, cavities at slab ends are not necessary be sealed with concrete;

The present work was a basis for start of slab manufacturing line at concrete articles plant in Sumy operating process and equipment of a British company «Spirol».

This process is basically different in application of Ukrainian-made steel cables as pre-stressed reinforcement instead of more expensive high strength wires in foreign counterparts.

Manufacturing process of the above slabs includes such stages:

-preparation of stands of 120 m long (two parallel operating manufacturing) which are cleaned and oiled;

-tensioning of operating reinforcement cables up to design value of and their rigid fixation on rests;

-slab forming by extruder machine, which makes the structure all over stand length. Forming takes place in horizontal plane, with extruder repelling from formed article, thus, ensuring uniform slab concrete compaction over its height;

-thermal treatment – structure covering with insulation material and stand heating from downside. After concrete has gained necessary strength, the slab is cut into pieces of necessary length with a laser device. Slabs may be cut both normal to their walls or obliquely. Cut slabs with cavities are removed from manufacturing line by lifting grips.

Nowadays after pilot operation period the slab manufacturing line works at full capacity. Construction units where the described structures are applied are characterized with high quality of finished flooring disks.

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