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TWO-DIMENSIONAL MODEL OF CALCULATION OF REINFORCED-CONCRETE COMPOSITE BEAMS BY THE METHOD OF CONCENTRATED DEFORMATIONS

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ABSTRACT

The article offers the construction of slab casts over precast joists with the use of steel profiled flooring and formation of two-dimensional model of calculation of reinforced-concrete composite beams with flexible ties by the method of concentrated deformations, the results of experimental and theoretical research, and comparison of the results. The method of concentrated deformations is the most precise to describe the work of combined beams with ties on linear and non-linear work, non-linear work of components, and has possibilities for accounting of real diagram of ties operation and deformation of components' materials.

Keywords: steel profiled flooring, flooring corrugated pipe.

INTRODUCTION

In the practice of construction of industrial and civil buildings, the most labor-intensive are works on solid-cast areas of lift slab. Application of solid-cast reinforced-concrete lift slabs is pre-determined by large number of holes, embedded items, anchors, and openings during construction of buildings with complex configuration, during repairs and reconstruction of buildings in confined areas, etc. The most labor-intensive and long works during construction of solid-cast lift slabs of traditional variant are formworks. The use of flitch shields of multiple turnover, sliding and travelling forms during placement of various solid-cast areas on high level requires significant labor expenses, a lot of timber, and hard manual labor. Cost of formwork and reinforcing constitutes 25-50%, labor intensity - 43-70% [11]. A perspective direction for solving the tasks of industrialization of construction, reduction of labor and material resources, reduction of construction time, and reconstruction of civil buildings and working enterprises is the application of steel floorings as formwork-armature of solid-cast reinforced-concrete lift slabs. The positive factors which cause wide application of combined lift slabs with external armoring, especially abroad, are: reduction of labor-intensity of construction by 1.5-1.7 times as compared to traditional monolith lift slabs and reduction of construction time by 25%; reduction of weight of lift slab, which causes reduction of cost of framework and foundations; significant reduction of volume of timber required for formwork; no need for scaffolding and the possibility for use free territories for storage; possibility and simplicity for placement of engineering communications within the height of lift slab and convenience of their transportation and repairs; initial toughness of lift slab against the influence of wind load[12, 13, 14, 15,16, 17].The performed research [15] showed that application of profiled sheet armature during construction of solid-cast lift slabs, as compared to traditional one, reduces the required volume of concrete by 36.6%, of steel - by 6.4%, with the equal cost. Also, labor costs reduced by 40.5%, total labor costs reduced by 45.6%. It is necessary to note inexpedience of the variant when joint work of beams with the slab is not ensures, which leads to excess expenditure of steel by 31.5%, increase of cost by 18.4%, and increases labor cost for construction by 31.9%. Provision of combined work of steel beams with concrete flange reduced steel expenditures by 15-34%, and strengthening of beams in the area of maximal efforts by steel stripe - by another 14-24%. It is known that application of reinforced-concrete girders during construction of lift slabs multistory buildings reduces their steel intensity. The use of collective prestressed reinforced-concrete girders as a bearing element of lift slabs instead of steel ones reduces steel expenditures by 22.1%, cost – by 5.2%, labor cost during construction – by 34.5%, and total labor cost – by 11.2%. At that, concrete expenditures increase by 21.4%[15].

However, in the system of combined lift slabs, application of assembly reinforced-concrete girders isn't popular. This is caused by lack of reliable and economical - in terms of labor and material expenditures – system of combining the slab with the girder, and relatively large weight of reinforced-concrete beams. There was offered a construction of lift slab in which steel flooring is put onto assembly reinforced-concrete girders with ledged on upper surface which repeat the profile of flooring[18]. According to the results of the experience[18], such combination provides unity of work of slab and girders. At that, application of such girders in practice has some difficulties: range of floorings requires production of specific formwork for girders; it's necessary to ensure high precision during manufacture of the items; connectors of girders require a lot of attention and care during transportation and storage. Also, there is construction of reinforced-concrete girders [18] with metal stripe on the upper surface for welding the fingers from reinforcement rods as T-piece. It is obvious that girders of such construction are peculiar for increase of labor intensity and metal intensity during their manufacture. The use of such girder in lift slab does not reduce labor cost for construction.

There is construction of combined lift slab[19], which excludes the above drawbacks. In this construction, lift slab of reinforced-concrete girder has rods which later serve as anchor of solid-casts lab. In armature-formwork, the gaps of anchors are filled with petals done by cutting the flooring along the lines of corrugated pipe and the following bending.

At present, a very actual issue is reconstruction of buildings of long-shut and aged enterprises and workshops. The Government of Kyrgyzstan set the task of reanimating the enterprises that have been shut since the Soviet period and creation of new jobs in each region of the republic by means of that[25]. Start of enterprises with new equipment and new technologies requires reconstruction of workshops, their re-design for new conditions of functioning. Under the conditions of reconstruction and re-design of workshops, the use of steel flooringsas armature-formwork for monolith lift slabis an industrial method. For this purpose, it is possible to use the offered construction of assembly monolith reinforced-concretelift slab[19].

In multi-story buildings, composite beam is technically a bending element consisting of reinforced-concrete slab and girders. Bearing capacity and deformation of such reinforced-concrete constructions is determined by toughness of the elements and ties between them. When there's no deformation of shift on the contact "slab – floor girder", composite beam could be viewed as monolith. However, such supposition does not characterize the work of such constructions strictly, as there is mutual shift of elements with ties of any level of toughness.

Different approaches are used for calculation ofcomposite beams. In bridge constructions, composite beams are calculated by the method of transformed section[20, 21].These works took into account plastic work of concrete and limited development of plastic deformationsof steel in steel beam belt. The works[22, 23]offer to calculate such constructions asreinforced-concreteconstructions with tough armature. The offered methodologies are fair for calculation of composite beams with tough and strong ties, the bends of which are determined according to the rules of construction mechanics in view of short-term and long-term concrete creep. The work [24]studied the joint work of composite beams with steel and reinforced-concrete girders of connector ties with solid-casts lab, armored by steel profiled floorings. Composite beams with steel beams have formulas for determination of bending moments depending on location of neutral axis - in the upper flange and it crosses wall of steel girder. The work notes that composite beam with assembly reinforced-concrete girder of the offered construction ensures full combination of work of the components. Based on this, calculation for bearing capacity and deformations is offered to be performed for monolith reinforced-concrete bending element according to the methodology norm[10].The work[26]was also devoted to study of the work of such construction, but it was aimed at automatization and optimization of design of steel reinforced-concrete lift slab in frame of multistory building.

The purpose of this research is creation of economical materials with low labor cost, technological and convenient for placement of engineering communications within the height of slab, and reliable during exploitation in various conditions of constructionof assembly solid-castconstructionreinforced-concretelift slabwith the use ofsteel flooringand methodology of itscalculationin view of flexibility of ties between slaband girder.

Composite beamof lift slab (Figure-1), consisting of a usual reinforced-concrete girder and flange - solid-casts lab for steel flooring, for the first case, could be viewed as two-dimensional task of reinforced-concrete.

Such calculation model supposes, as to the T-piece form beam profile, that overhangs do not bend in broadside direction, and the whole flange with full width is included into work in longitudinal direction. This supposition comes out of constructive peculiarities of the viewed lift slab, where the slab has relatively small case bays (up to 3 m) and has large toughness in the direction of flooring corrugated pipes.

The next condition for this model – upper flange-slab is involved into joint work with girder in longitudinal direction equally along all width of the flange, starting from the base, where shearing force for the contact of flange and the girder web is the largest.

Correctness of this admission has been verified in the experiments which showed practical equality of longitudinal deformations in the slab flange along its width along the whole beam bay[9].

Calculation model for composite beam can be more complicated, three-dimensional, but in this work we form a two-dimensional calculation model of assembly solid-cast reinforced-concrete composite beam.

Among various methods of calculation of plain-strained reinforced-concrete constructions, the most universal and simple one is the method of final elements (MFE)[1, 2, 3, 4, etc.]. However, the method of concentrated deformations (MCD) has some additional advantages[5, 8]:

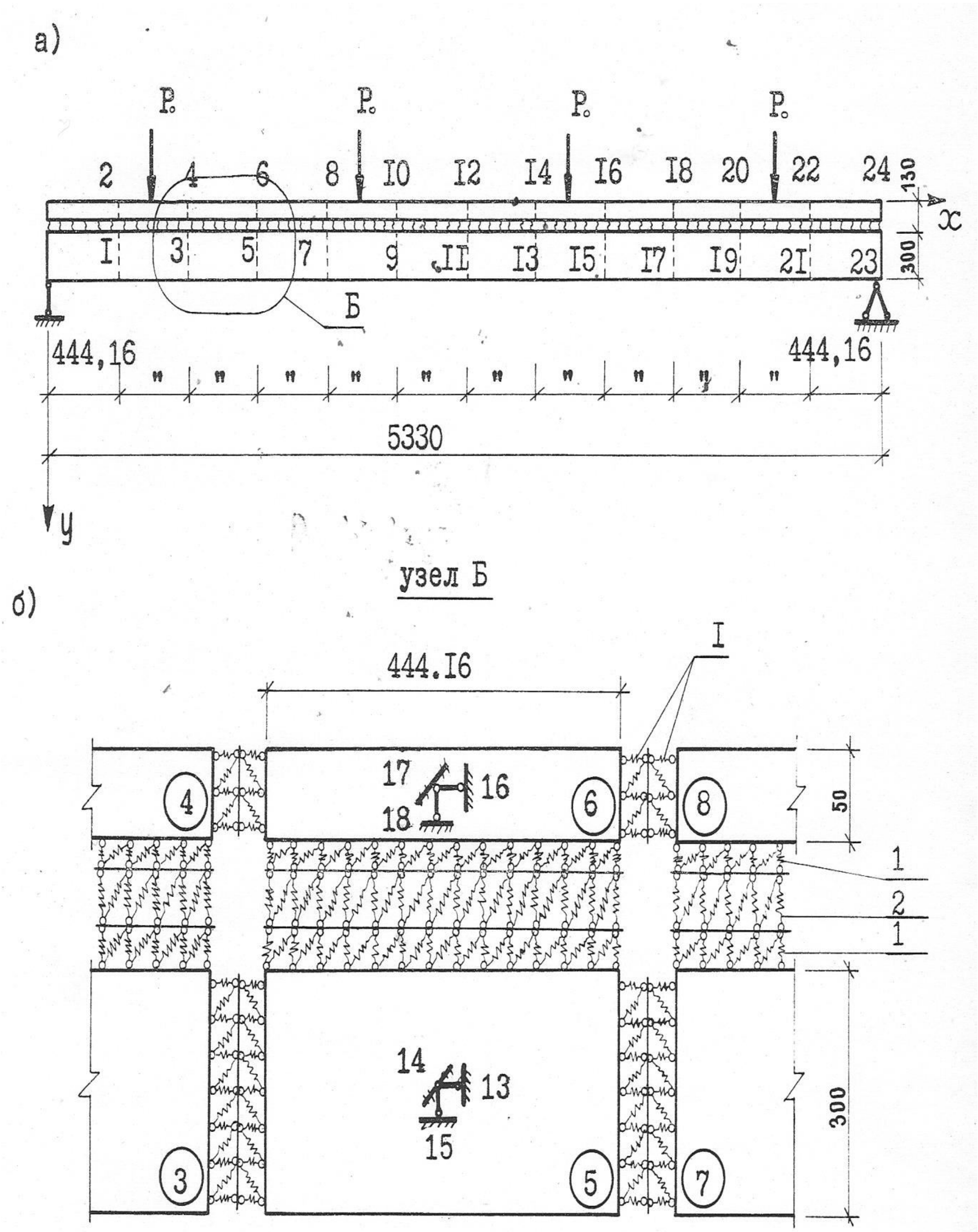

Figure-1. Calculation model of composite beam.
a) - lay-out chart of construction; b) - elements and ties of the method of concentrated deformations.
1-mock seams; 2- real seams.

Firstly, size of the element of MCD could be larger than with MFE, under the conditions of provision of the same precision of calculation. This is explained by the fact that MCD – unlike MFE – allows for variable field for movements, deformations, strains, and modules of deformations; secondly, with the equal level of discretization, the number of the unknown in MCD is much larger than with MFE (with nodes with three freedom levels).

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Theoretical study of composite beamsis based onMCD, developed in$[5, 6, 7, 8, 9, etc.]$. This research distinguished three stages: the first stage - consideration of tense stage of work of elements and their ties; the second stage - non-linear work of arris ties between slab flange and girder, with elastic work of the latter; the third stage - study of inelastic work of components (slabandgirder) and arris between them.

Calculation modelof composite beamis presented in Figure-1,a. The level of discretization of constructionalong the length for elements ofMCDis usually determined by the required precision of calculation.Satisfactory precision of calculation is achieved, with the given tension and limit conditions, by division of this construction into six elements.

Verticalflat surfacesof concentrated deformations (CD) produce ties ofMCD, toughnessof which is determined by features of materials and profiles of girder andslab; horizontalflat surfaces includes real ties of shift between components of the combined construction. Real and own ties, working by the scheme of successive connection, create complex ties of MCD (Figure-1, b).

Usually, strength and toughnessof such beams withslabfor steel flooringis determined mainly by characteristics of usual profiles of girders (Figure-3, a) and shift characteristics (Figure-2).

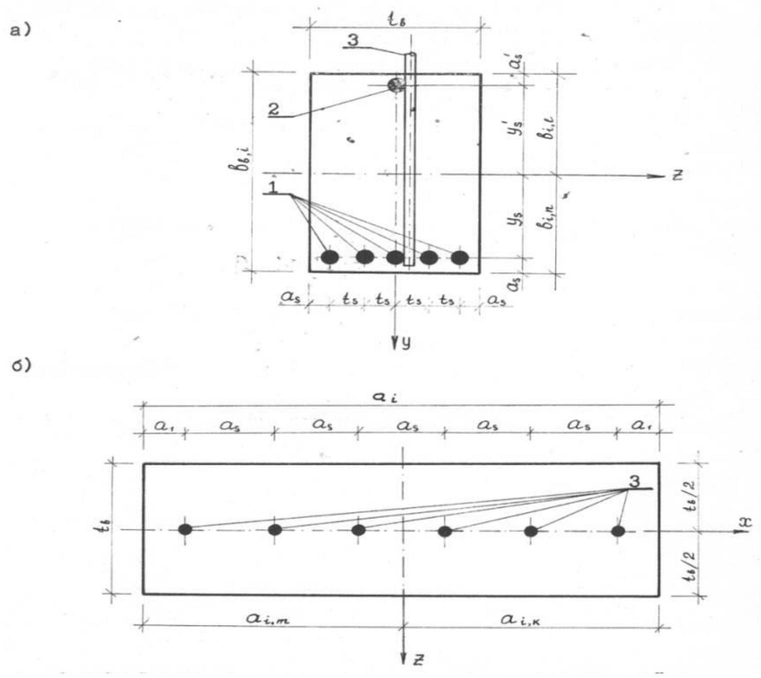

Figure-2. Calculation model ofcomposite beam.a) - lay-out chart;
b)-scheme of internal forces

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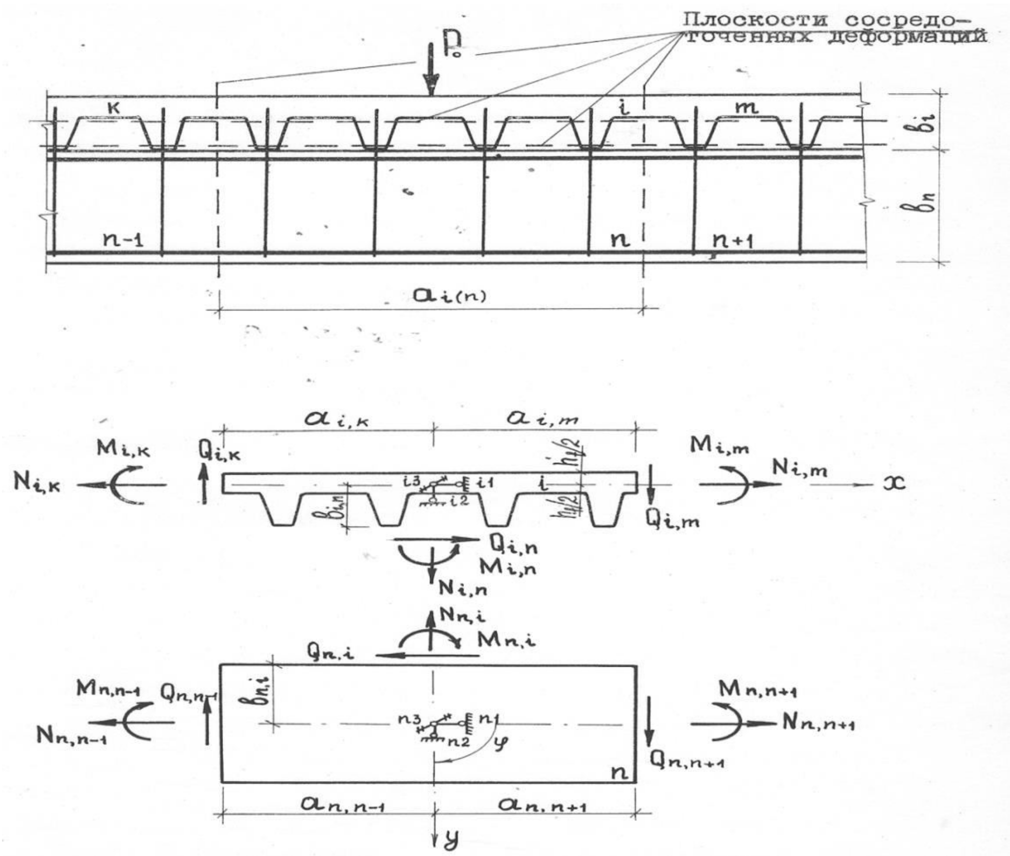

Figure-3. Profile of girders by planes of concentrated deformations.
a) -vertical planes; b) - horizontal planes; 1 - long tension reinforcement ($5\emptyset 20\ A-III$);
2 -compression reinforcement ($\emptyset 20\ A-III$); 3 - vertical anchors-rods($\emptyset 14\ A-III$)
2, b)arris ties between slabandgirder.

Characteristics of profiles of slab along the waves (Figure-4, a) could be deemed insignificant, as with the width b_i = 5 cm and one-sheet armoring, toughnessand strength of such profiles will be not high, and it is possible to suppose that such slab in the direction across the waves does not take bending moment, but it's necessary to take into account normal and shear forces.

In the direction of shift between the slab and girder, deformation of contact "slab- floor girder" through vertical arris of slab and flexible rod anchors will be decisive; at the same time, toughness of such connection in the direction from the slab to floor girder is very large.

Along the height of composite beam (Figure-2, a) it is possible to make two horizontal flat surfaces CD. With such cutting, flanges lab is viewed as independent element of MCD, and vertical flanges are considered to be real ties of combination of elements of slab and girders.

As is seen from Figure-2, b, in the offered calculation model, internal forces between girder and slab are related only to one flat surface of CD - upper surface of girders.

Each tough element of MCD possesses three levels of freedom – it can move translationally by the value $U_i$in the direction of axes Xand Y and rotate by the angle $\varphi_i$inflat surfacesof assembly beam (Figure-2, b).

The calculation includes full diagrams "σ–ε" for concrete and armature, received under the conditions of uniaxial compression and extension of model samples, and diagrams of deformation of real ties with the shift "S-Δ"[9].

According to MCD, conditions of balance of the system is expressed by the matrix equation of the type

$$[\boldsymbol{R}] * \{\boldsymbol{\omega}\} = \{\boldsymbol{P}\},(1)$$

where$[R]$- matrix of external toughness of the system;
$\{\omega\}$-vector of movements;
$\{P\}$-vector of external forces.

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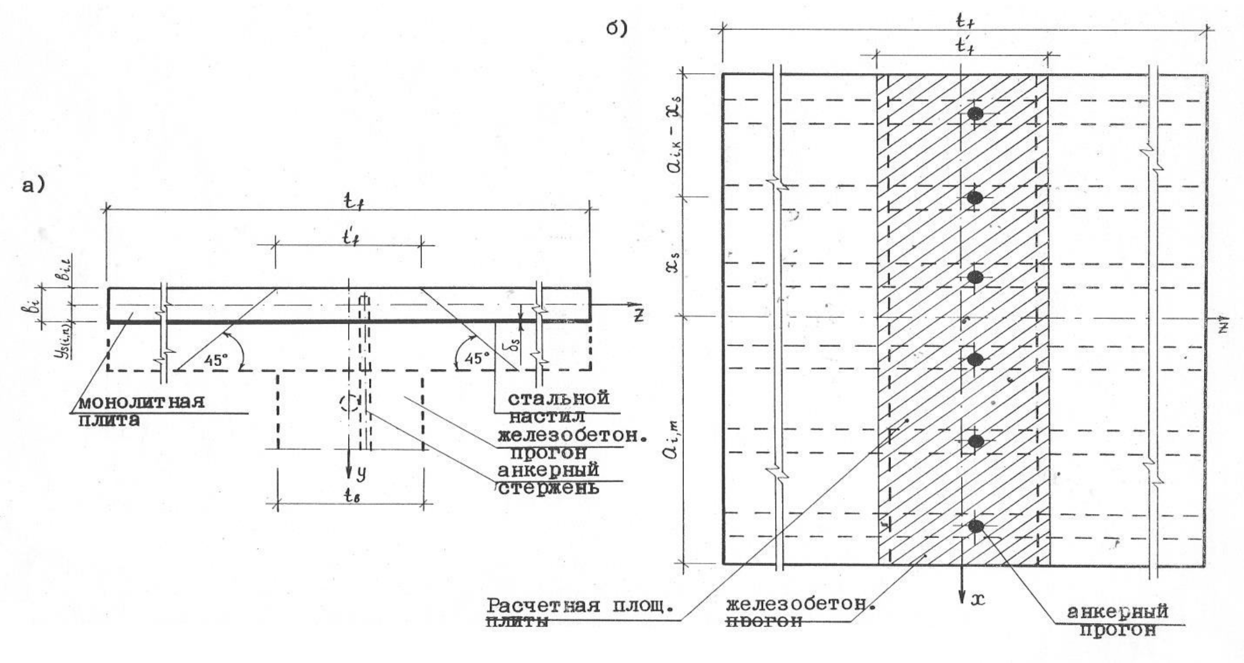

Figure-4. Profile of solid-castslab by planes of concentrated deformationsa) - vertical planes; b) - horizontal plane.

For the whole system, the global numeration of the elements of MCD and connections of the method of movements should be conducted for the short direction (in this case - bottom-up-right); at that, the width of the matrix of external toughness$[R]$will be relatively narrow. With such numeration (Figure-1, a), the number of elements of the calculated construction in short direction will constitute m = 2, and the width of the stripe will constitute L = 3x2+2 = 8.

Connection between internal forces for planes of CD and corresponding deformations is expressed in the form

$$\{F\}= [\boldsymbol{C}] * \{\boldsymbol{\lambda}\}, \quad (2)$$

where$\{F\}$- vector of internal efforts;
$[C]$-matrix of internal toughness of profiles;
$\{\lambda\}$-vector CD (mutual shifts and turns of elements of MCD).

For all profiles of MCD elements for CD planes, the hypothesis of plane sections is undertaken. Profile of girdersfor height was divided into twenty elementary stripes, within which deformations were constant. In the spots of armature location the stripe was equaled to the rod diameter. Profile of slabwas divided into eight equal parts. Along the length, the construction is divided into twelve equal parts.

The results are expressed by movements, mutual shifts, and internal forces of elements of the bearing system for provision of toughness for normal profiles. If necessary, the calculation may contain the conditions of toughness for inclined profiles. The calculation also verifies the bearing capacity of accepted profiles with the set external forces, or the values of the latter are found at which the construction will be destroyed.

Figure-5 shows the bends of the middle of place section of composite beam at different levels of loading, received by experimental and calculation methods. As is seen from the graph, the data of the test and calculation coordinate with each other, and the difference is 1.0-16%. Figure-5 shows symbols B-2-1 for test samples without the upper slab, i.e., only for reinforced-concrete girders, and B-2-2 – for composite beam with upper slab on steel flooring. The graph for the sample B-2-1 shows the results of the calculation for[10].

Figure-6 shows experimental and calculation diagrams of deformation of concrete of f lange,girders (a), and positive reinforcement (b) in the middle of place section of the construction. As is seen from the figure, these data are very similar.

Based on the performed research, the following conclusions are made: the developed construction of assembly monolithreinforced-concretelift slabreduced metal cost and labor cost during the construction; composite beamwith shift ties could be calculated by the method of concentrated deformations (MCD) with high level of precision; during application ofMCD, the level of discretization of elements is lower than with the application of MFE; for practical calculations ofcomposite beamswith case bay 6.0 m, it suffices to take up the scheme of division for the length into 12 parts, and discretization of profiles of slab- into 8-10, girders - into 16-20elementary stripes, depending on the height (width); with equal quantity of elements, the number of the unknown of the MCDmethod is much lower than with MFE (with nodes with three degrees of freedom); calculation of composite beams for the theory of MCD confirms the correctness of the built calculation model; at the stages of elastic and inelastic work of ties between

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flange and girder, during linear work of the latter, and during the non-linear work of components (slabs andgirders) ensures good convergences with the test results; the use incalculations of experimental diagrams of deformation of materials and adjustable ties allows for the precise description of real work of such constructions; the developed program allows determining the tense-deformed state of composite beamsat any level of load.

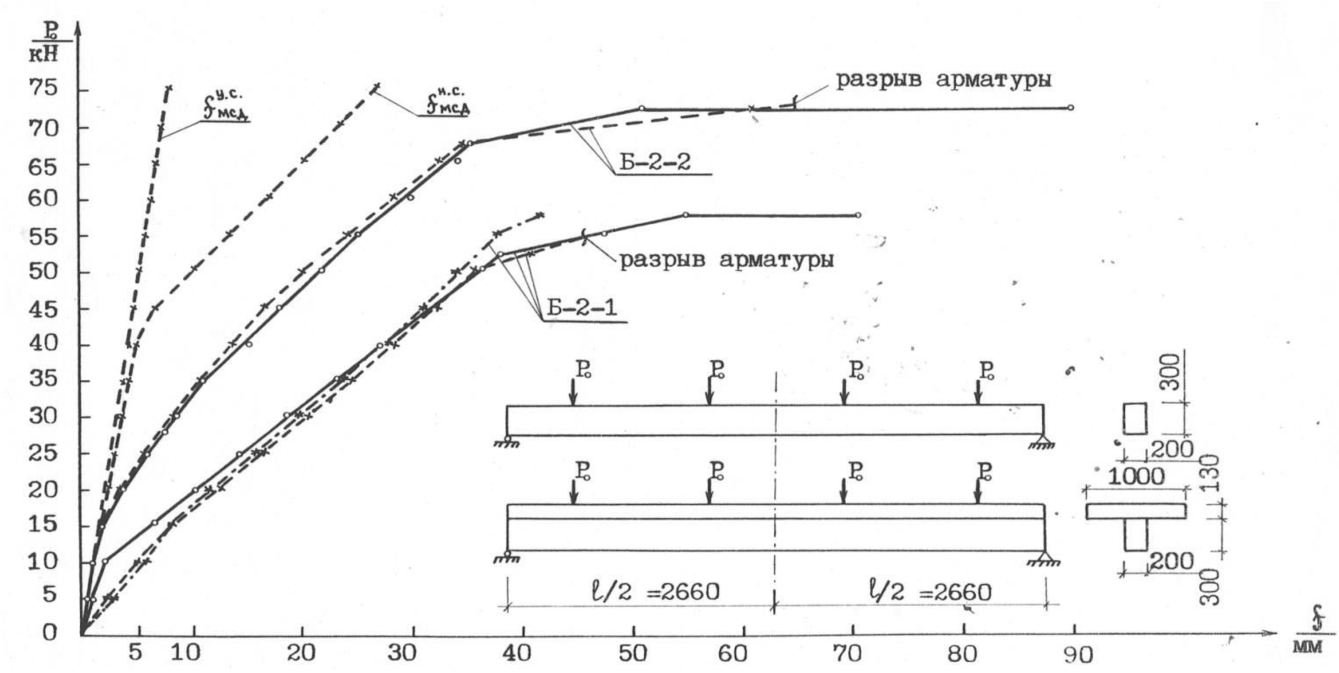

Figure-5. Bends of experimental samples.

—o— -data of experiment; —×—×— -data of calculation for MCD; -··-×-·- -data of calculation for SNiP; $f^{у.с}_{MCD}$– bends with elastic work of elements and ties between them; $f^{н.с}_{MCD}$– the same, in view of inelastic work of ties.

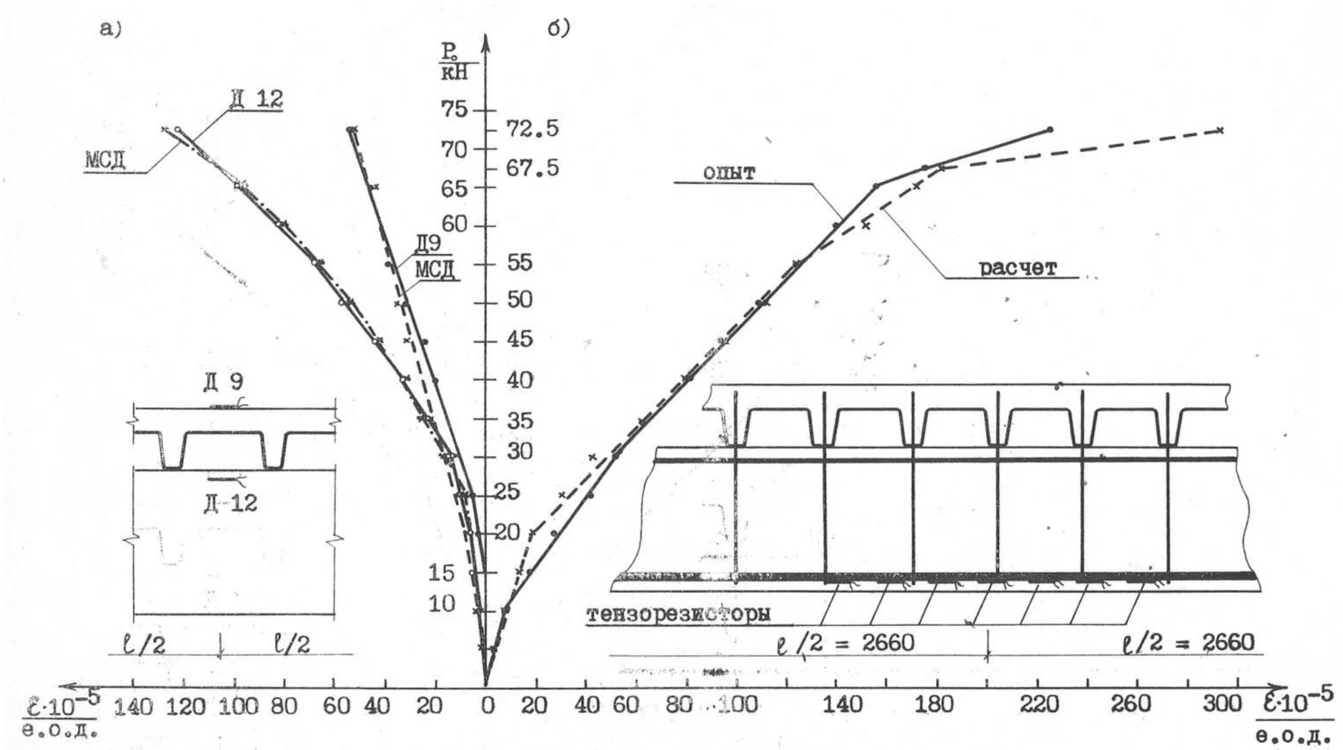

Figure-6. Diagrams of deformation of concrete (a) and armature (b) in the middle of case bay.

REFERENCES

[1] GenievG.A., TyupinG.A. 1968. Certain questions of the theory of elasticity and plasticity of reinforced-concrete with cracks. New methods of calculation of building constructions. M.: Stroyizdat.pp. 9-14.

[2] KarpenkoN.I. 1971. Regarding calculation of reinforced-concrete plates and shells in view of cracks. Construction mechanics and calculation of buildings.(1): 7-13.

[3] NosarevA.V. 1973. Approximate methods in the theory of armored materials and their approximation to calculation of building constructions. PhD thesis.M. p. 31.

[4] SkvirenkoS.M. 1978. One approximate method of calculation of thin elastic geometrically non-linear constructions. - Issues of strength and durability of elements of aviation constructions /Inter-university bulletin, Issue 4. - Kuybyshev.pp. 146-148.

[5] DodonovM.I. 1984. Development and application of the method of concentrated deformations to calculated of bay baffles of multi-story buildings. Construction mechanics and calculation of buildings.(6): 65-69.

[6] Dodonov M.I. 1986.Calculation of bending plates with the method of concentrated deformations. Construction mechanics and calculation of buildings. (2): 22-25.

[7] DodonovM.I. 1984.Development and application of the method of concentrated deformationsto the calculation of plane constructions of multi-story buildings. //Theses of reports of the 3rd coordination council. - Vilnius.pp. 84-88.

[8] DodonovM. I., TemikeevK., ZulpuyevA.M. 2012. Theory of concentrateddeformationsin applied tasks. BishkekIlim. p. 274.

[9] DodonovM. I., BaktygulovK.B. 1987. Experimental and theoretical study of assembly-solid-cast reinforced-concrete lift slabs with external armoring/Moscow engineering and Construction Institute. -M. 14. p. -No. 8438.

[10] 1985. SNiP 2.03.01-84. Concrete and reinforced-concrete construction. -M.p. 79.

[11] SannikovI.V. 1982. Study of solid-cast reinforced-concrete slabs with sheet profiled armature. -PhD theses. -Kyiv. p. 25.

[12] NakaryakovE. 1979. Non-recoverable formwork and working armature of the profiled sheet. Construction of metallurgic and chemical enterprises, Ministry of heavy construction of USSR. 1(11): 12-13.

[13] FilatovA.M. *et al*. 1979. Application of galvanized steel sheet as sheet armature for lift slabs of industrial buildings. Construction of metallurgic and chemical enterprises, Ministry of heavy construction of USSR. 1(11): 2-7.

[14] VoronkovR.V. 1978. Solid-cast ceiling slabs built without formwork. Design and calculation of building constructions. -L.: LDNTP.pp.73-80.

[15] PetrovI. A., RabinovichR.I., NargizyanE.A. 1981. Solid-castlift slabwith external armature made of steel profiled sheet. Industrial construction.(7): 11-13.

[16] 1974. Steel construction of buildings with steel reinforced-concrete ceiling slabs of CSSR. -M: CINIS, Collection of theses. 8(5): 8-11.

[17] AnshinL.Z. Steel reinforced-concrete construction of lift slabs and layer of civil buildings. Industrial construction, 1979, No. 5, p.14-15.

[18] RabinovichR.I., BogdanovA.A., KarpovskiyM.G. 1983. Joint work of slabs with profiled sheet armature and reinforced-concrete girders. Concrete and reinforced-concrete.(1): 33-34.

[19] DodonovM.I., BaktygulovK.B. 1988. Assembly monolith lift slab with steel profiled flooring. Concrete and reinforced-concrete.(4): 7-9.

[20] Gibshman E.E. 1956.Bridges with steel beams, combined with concreteslab. M.: Avtotranizdat. p. 232.

[21] StreletskiyN.N. 1981.Steel reinforced-concretebridge bays. M.: Transport. -360 c.

[22] RabinovichR.I. 1983.Sphere of application of existing methodology of calculation for strength of constructions with tough armature. Lift slabfor steel flooring. M.: Gosstroy of USSR.pp. 45-46.

[23] CP117. 1975. Composite construction in structural steel and concrete Part1: Simple supported beams in building. -London, George Codwin Limited. p. 125.

[24] KarpovskiyM.G. 1985. Joint work of beams with lift slabs armored with profiled steel flooring. - PhD thesis. M.: NIIRC. p. 152.

[25] 2015. The Program of the Government of the Kyrgyz Republic "Stability, trust, and new possibilities. Set by the decree of the Parliament of the Kyrgyz Republic dated November 5, No. 10-VI.

[26] 2004. Automatized optimal design of steel reinforced-concrete lift slabs. PhD thesis. -Ekaterinburg. p. 144.