Carrying capacity of strengthened reinforced elements on action of bending moments

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*Abstract.*The article proposes methods of calculation of carrying capacity of strengthened reinforced elements on action of bending moments. Basing on the experimental research, we have carried out analysis of calculated data with the investigated results.

*Keywords:*carrying capacity, strengthening, concrete, gunned concrete, strains.

INTRODUCTION

Increase of carrying capacity of reinforced elements (RE), without a change of a constructive scheme, expects increase of a cross cut of a strengthened sample and should be made with application of such material as concrete, polymer concrete, fibre-reinforced concrete, as well as reinforcement with carbon fiber-reinforced plastic stripes and bed. Strengthening of bending reinforced structures with gunned concrete, which can be put in thin layers of a structure reinforcement, is a method, being efficient and reliable in operation [1, 2, 3, 4, 5, 6, 7, 13, 19].

To secure safety of strengthened RE and improve methods of their calculations, one needs investigation of regularities of changes of sustainability, deformation ability of materials at different degrees of stress with applied reinforcement [1, 5, 9, 11, 13, 15, 17].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Investigation of reinforced structures are presented in the works of Ye.M. Babych, A.Ya.Barashykov, Z.Ya. Blikharskyi, S.V. Bondarenko, O.I. Valovyi, O.B. Holyshev, V.H. Kvasha, H.A. Molodchenko, L.A. Murashko, and others [1-20]. Basing on the researches, we studied effective constructive solutions on strengthening of reinforced structures and proposed methods of calculation.

On the ground of previous researches it is described [16, 17] how concrete and gunned concrete layers of the investigated elements work jointly, secured by adhesive padding with polymer mortars and installation of pasted metal land ties [20].

OBJECTIVES

Aim of the work is to make estimation of carrying capacity of strengthened reinforced elements on action of bending moments with consideration of the reinforcement technology. Task of the research is to develop methodology and make analysis of theoretical and experimental investigation of strengthened RE considering unrelieved stress to reinforcement fulfillment.

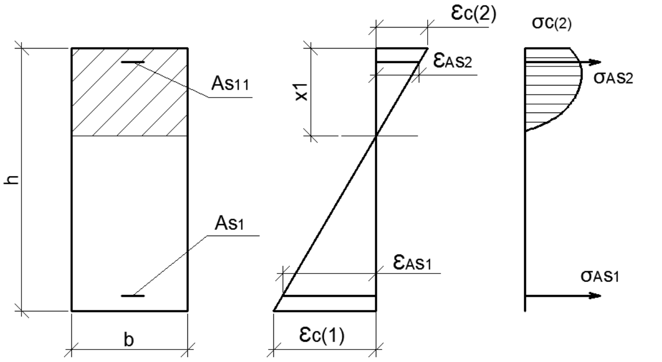
THE MAIN RESULTS OF THE RESEARCH

The presented calculation is based on the algorithm, mentioned in normative documents on the base of a deformation model, being modified according to a certain experimental research [7,8]. The algorithm is adopted for calculation of reinforced structures by different ways (lengthening, case or hooping) and considers their joint operation.

Base of the calculation is made by formulae (1.1), presented in SBN 2.6-98 on calculation of stress strain behavior of rectangular cuts in case of eccentric extrusion and bend (fig. 1), describing equilibrium in a cut in the integral form:

$$\begin{cases} \Sigma M := \dfrac{b \cdot f_{cd}}{N_{pr}^{\;2}} \cdot \displaystyle\int_0^{y_1} \sum_{i=1}^{5} a_i \cdot y^{i+1} dy + \sum_{i=1}^{3} \sigma_{s_i} \cdot A_{s_i} \cdot \left(x_1 - z_{s_i}\right); \\ \Sigma x := \dfrac{b \cdot f_{cd}}{N_{pr}} \cdot \displaystyle\int_0^{y_1} \left(\sum_{i=1}^{5} a_i \cdot y^{i} \right) dy + \sum_{i=1}^{3} \sigma_{s_i} \cdot A_{s_i}; \end{cases} \quad (1)$$

where $\aleph = \frac{1}{\rho} = \frac{(\varepsilon_{c(1)} - \varepsilon_{c(2)})}{h}$ - is a bowing of bended gridline in a cut; $\varepsilon_{c(1)}$, $\varepsilon_{c(2)}$ - strains of concrete of stressed and positive fiber respectively; $\gamma = \frac{\varepsilon_{c(1)}}{\varepsilon_{c1}}$, where ε_{c1} is a value of critical strains of concrete of stressed fiber; $x_1 = \varepsilon_{c(1)} / \aleph$ - is a height of the stressed zone; $\overline{\aleph} = \aleph / \varepsilon_{c1}$ - relative bowing; z_{si} - distance of i rod or interlayer of reinforcement from the most stressed border of a cut.



a **b** **c**

Fig. 1. Stress strain behavior of a rectangular cut: **a** – cross cut of an element; **b** – strain diagram at equilibrium; **c** – stress diagram.

A joint operation of an "old" and "new" concrete is measured by assigning of a common deflection to all elements of the cut and the deflection is calculated according to the formula:

$$f = \frac{1}{r} k_m l^2. \qquad (2)$$

Because in the formula 2 all values, except bowing $\frac{1}{r} = \frac{\varepsilon_{c_{11}} - \varepsilon_{c_{12}}}{h}$, are constants, to secure an equal deflection at all stages of the beam operation, it is sufficiently that bowing growth to be the same from the moment of enforcement for all parts. This condition can be outlined in the following way:

$$\frac{\left(\varepsilon_{c_{11}} - \varepsilon_{c_{11\_0}}\right) - \left(\varepsilon_{c_{12}} - \varepsilon_{c_{12\_0}}\right)}{h} = \frac{\varepsilon_{c_{21}} - \varepsilon_{c_{22}}}{h + h_1 + h_2}; \qquad (3)$$

where $\varepsilon_{c_{11\_0}}$, $\varepsilon_{c_{12\_0}}$ - is for strains at upper and down border of an old part of the beam at a moment of reinforcement; $\varepsilon_{c_{11}} - \varepsilon_{c_{11\_0}}$, $\varepsilon_{c_{12}} - \varepsilon_{c_{12\_0}}$ - is a growth of strains at upper and down border of an old part of the beam from a moment of reinforcement respectively; $\varepsilon_{c_{21}}$, $\varepsilon_{c_{22}}$ - strains at upper and down borders of a new part of the beam respectively, obtaining non-zero value from a moment of reinforcement.

In the equation 1.3 there are two unknowns: $\varepsilon_{c_{21}}$, $\varepsilon_{c_{22}}$. To calculate them, one of them is assigned with a gradually growing value, and the other is calculated. The procedure is repeated until the found values satisfy an equilibrium equation (4).

Estimation of stress strain behavior of strengthened reinforced beams, having a joint operation of old and enforced parts as one of the principal criteria, can be presented in the equation (4, 5), general picture of which are demonstrated in the integral form.

$$\Sigma x = \frac{b_1 \cdot f_{cd_2}}{N_{pr}} \cdot \int_0^{y_{22}} \left(\sum_{i=1}^{5} a_{20+i} \cdot y^i \right) dy + \frac{b_2 \cdot f_{cd_2}}{N_{pr}} \cdot \int_0^{y_{22}} \left(\sum_{i=1}^{5} a_{20+i} \cdot y^i \right) dy$$
$$+ \frac{b \cdot f_{cd_2}}{N_{pr}} \cdot \int_{y_{21}}^{y_{22}} \left(\sum_{i=1}^{5} a_{20+i} \cdot y^i \right) dy + \sum_{i=1}^{3} \sigma_{s_{20+i}} \cdot A_{s_{20+i}}; \qquad (4)$$

To satisfy conditions of equilibrium we find a value of a moment *(M)*, excepted by each part of a cut:

- for a principal part of a beam

$$\mathbf{M}_1 := \frac{b \cdot f_{cd_1}}{N_{pr}^{\;2}} \cdot \int_0^{y_1} \sum_{i=1}^{5} a_{1+i} \cdot y^{i+1} dy + \sum_{i=1}^{3} \sigma_{s_{1+i}} \cdot A_{s_{1+i}} \cdot \left(x_1 - z_{s_{1+i}}\right); \qquad (5)$$

- for a reinforced part of a beam

$$\mathbf{M}_2 := \frac{b_1 \cdot f_{cd_2}}{N_{pr}^{\;2}} \cdot \int_0^{y_{22}} \sum_{i=1}^{5} a_{20+i} \cdot y^{i+1} dy + \frac{b_2 \cdot f_{cd_2}}{N_{pr}^{\;2}} \cdot \int_0^{y_{22}} \sum_{i=1}^{5} a_{20+i} \cdot y^{i+1} dy +$$
$$+ \frac{b \cdot f_{cd_2}}{N_{pr}^{\;2}} \cdot \int_{y_{21}}^{y_{22}} \sum_{i=1}^{5} a_{20+i} \cdot y^{i+1} dy + \sum_{i=1}^{3} \sigma_{s_{20+i}} \cdot A_{s_{20+i}} \cdot \left(x_2 - z_{s_{20+i}}\right); \qquad (6)$$

Total value of a moment is got by addition of corresponding moments, resulted from the previous equations:

$$M = M_1 + M_2 \qquad (7)$$

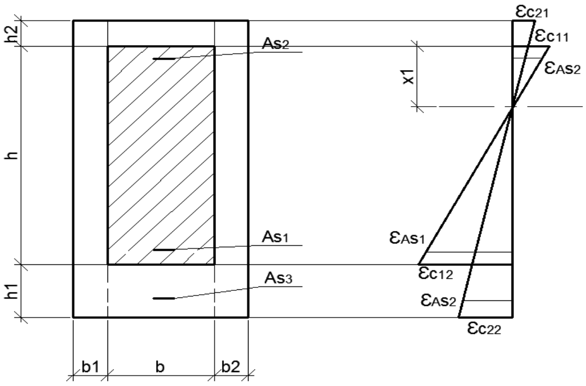


Fig.2. Scheme of stress strain behavior of a rectangular cut being reinforced

Calculation algorithm is presented at fig.3.

Series of the carried research consisted of fifteen investigated beams of projected sizes (Lxhxb) 2300x200x80(120;145). The beams under research are made reinforced (f_{cd}=23,5 MPa) by common technology, beam (B-2) without reinforcement, nine beams are reinforced by lengthening with gunned concrete technology (B-2-1…eg) and four beams are reinforced by usual concreting of input frames (B-2-2…uc). Beams are reinforced at different degrees of stress: 0,0; 0,3; 0,45; 0,6 from a critical moment, and thus got corresponding marks. In all cases of reinforcement we used adhesive padding Koster SB –Haftemulsion and metal joining land ties (Ø 8mm), projecting above the surface at 35mm. Class of the concrete of reinforcement layer for beams (B-2-1-1… eg, B-2-1-1.2…eg) - f_{cd}= 28,3 MPa, for beams (B-2-1-2… eg - f_{cd}= 23,6 MPa, and for (B-2-2-1…uc, B-2-3-1.2…uc) beams - f_{cd}= 24,1 MPa.

On the first stage of the experiment, non-reinforced beams were tested with centered stress, when loading step was equal 0;1F from a critical one. Process of beams investigation was made according to a static scheme, i.e. a beam on two supports, with a span *L*=2100 mm. When fluid behavior was achieved, the examples were relieved, their critical operation stress was taken as a control one for all beam samples being reinforced.

Next stage of the work included reinforcement of the beams under experiment (fig.4).

The main method was to apply an reinforcing layer of concrete or gunned concrete, which was put on a side surface (on one or both sides) with a previous flat reinforced frame.

Testing of the beams under experiment was made on the 440th-676th day from a date of production and on the 45th-72nd day from a date of reinforcement by application of concentrated forces in one third of their span. Experimental and calculated values of bending moments, corresponding to critical conditions and destruction, as well as their comparison are presented in the table 1.

Table 1. Strength of reinforced experimental beams

№	Beam code	Geometric sizes (reinforced) bxh, mm	Degree of stress	Value of bending moments, M, kH m		$\frac{M_u^{exper}}{M_u^{SBN}}$
				experiment, critical	calculation according to SBN [7;8]	
1	B-2	80x200		19,04	18,853	1,01
2	B-2-1-1-0,0-eg	80x200 (120x200)	0,0	30,62	29,651	1,032
3	B-2-1-1-0,3-eg	79x200 (120x200)	0,32	30,425	29,599	1,028
4	B-2-1-1-0,6-eg	80x200 (120x200)	0,62	28,84	27,274	1,057
5	B-2-1-2-0,0-eg	77x196 (120x196)	0,0	29,155	27,893	1,045
6	B-2-1-2-0,3-eg	77x196 (120x196)	0,31	28,08	26,988	1,040
7	B-2-1-2-0,6-eg	77x196 (120x196)	0,61	26,05	24,938	1,045
8	B-2-2-1-0,0-uc	79x200 (120x200)	0,0	29,86	29,304	1,019
9	B-2-2-1-0,3-uc	80x200 (120x200)	0,32	29,25	29,095	1,005
10	B-2-2-1-0,6-uc	80x200 (120x200)	0,62	24,48	27,031	0,905
11	B-2-2-1.2-0,0-uc	77x203 (148x204)	0,0	37,05	35, 26	1,051
12	B-2-2-1.2-0,45-uc	78x204 (148x204)	0,45	33,06	31,31	1.056
13	B-2-1-1.2-0,0-eg	77x203 (144x203)	0,0	34,66	33,165	1.045
14	B-2-1-1.2-0,3-eg	78x202 (145x202)	0,33	34,64	33,034	1.049
15	B-2-1-1.2-0,6-eg	78x203 (145x203)	0,63	29,75	28,20	1,055

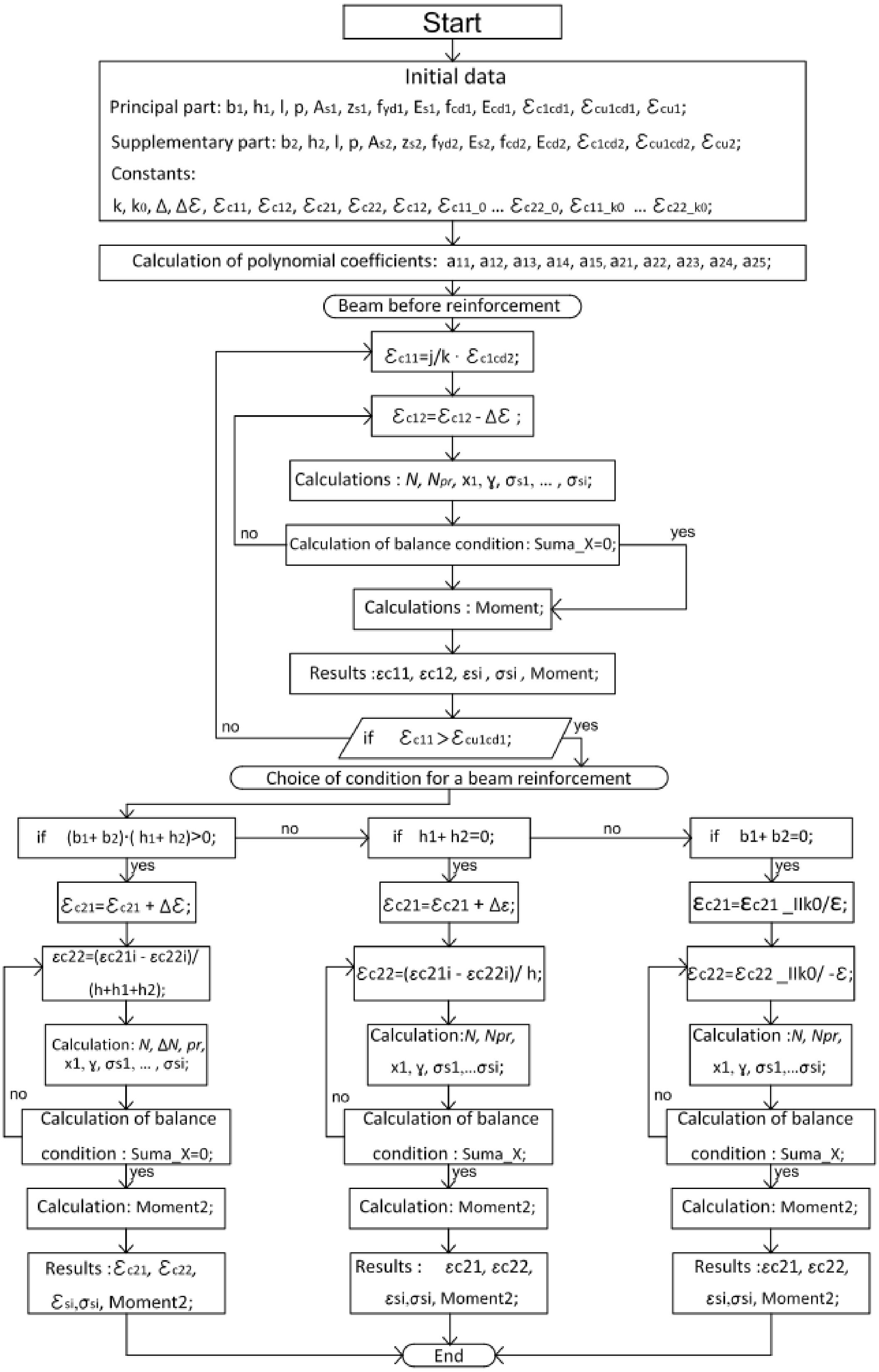


Fig. 3. Block-scheme of calculation on strengthening of reinforced beams

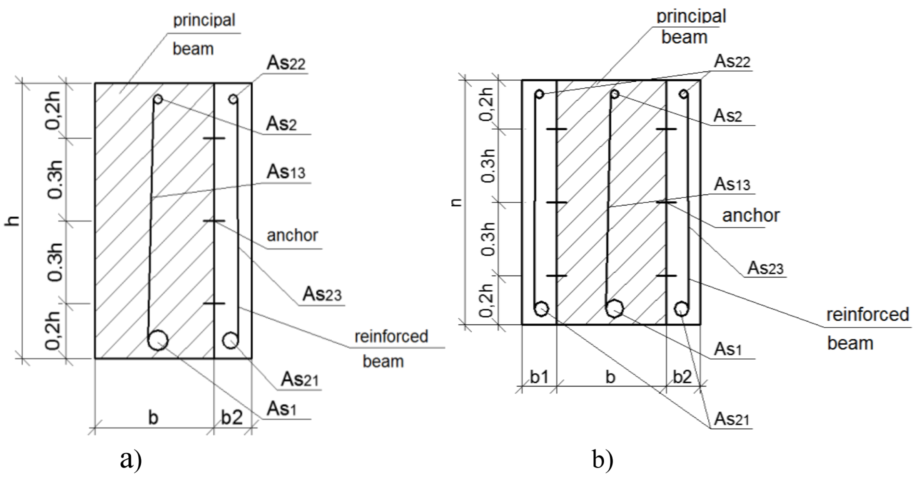


Fig. 4. Scheme of reinforcement of a side surface of experimental samples:
a) B-2-1-1, B-2-1-2, B-2-2-1; b) B-2-2-1.2, B-2-1-1.2

Having got results of experimental researches and compared them with the proposed calculation (see table 1), one can make a conclusion that theoretical and experimental values coincide, and deviation is less than 6%. It proves the fact that the suggested algorithm makes qualitative estimation of the process of RE strengthening at different degrees of stress (up to 0,62 from a critical one).

Dependence of strains on stress for beams at height of a cut has the same results as (fig 5,6), we used results of a beam B-2-1-2-0eg to be described in the article.

Diagrams of dependence of strains on stress in the beam B-2-1-2-0 eg at height of a cut are presented in (fig. 5,6), and demonstrated distribution of strains at height of a cut (h=20, for armature 170 mm). The presented graphic dependences prove that at different cuts (h=20 and h=60) theoretical and calculated values differ. Thus, for example, at operation degree of stress of 0.7 M in a cut h= 20 mm, in a principal part of the beam the difference makes 8-14% in the reinforced part 10-20%. In a cut h= 60 mm close to neutral axis, the difference in two parts of the beam makes 10-14%. Diagrams of armature strains at h= 170 mm show a deviation of values in the principal part of the beam 6-11% and in the reinforced part – 12-28%. We consider that such difference of calculated and experimental values of principal and reinforced parts of the beam is caused by late start of operation of armature in the reinforced part.

CONCLUSIONS

Analysis of the carried experimental and theoretical researches demonstrates that, according to the acting norms, methodology of calculation of carrying capacity of normal cuts of strengthened reinforced beams, made by a corresponding algorithm, gives a satisfactory result, and the deviation makes up to 6%. However, at height of a cut, value of experimental and calculated strains gives larger difference (10-20%), especially armature of reinforced parts 12-28%. Thus, in the further researches it is necessary to increase number of cuts for comparison and consider a larger range of stress degrees on reinforcement.

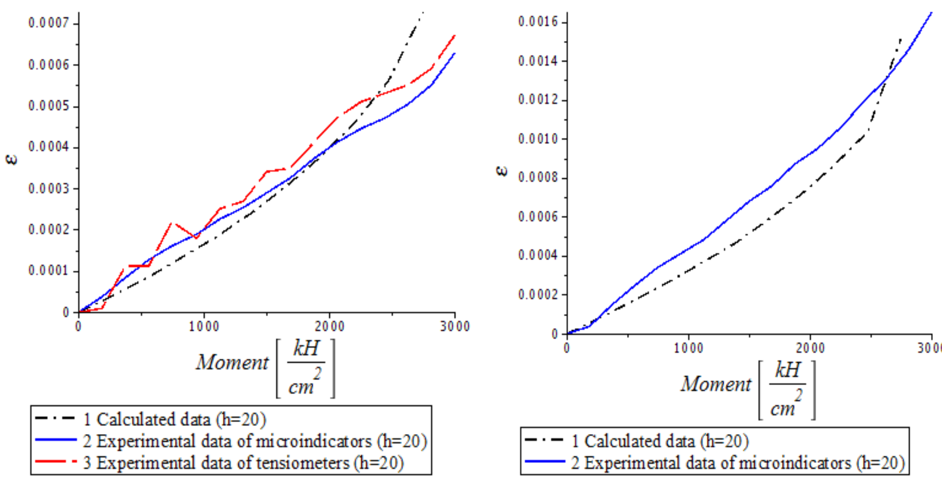


Fig. 5. Diagram of strains dependence on stress in the beam B-2-1-2-0 eg at height (h=20 mm): a) – principal part of the beam, b) reinforced part of the beam

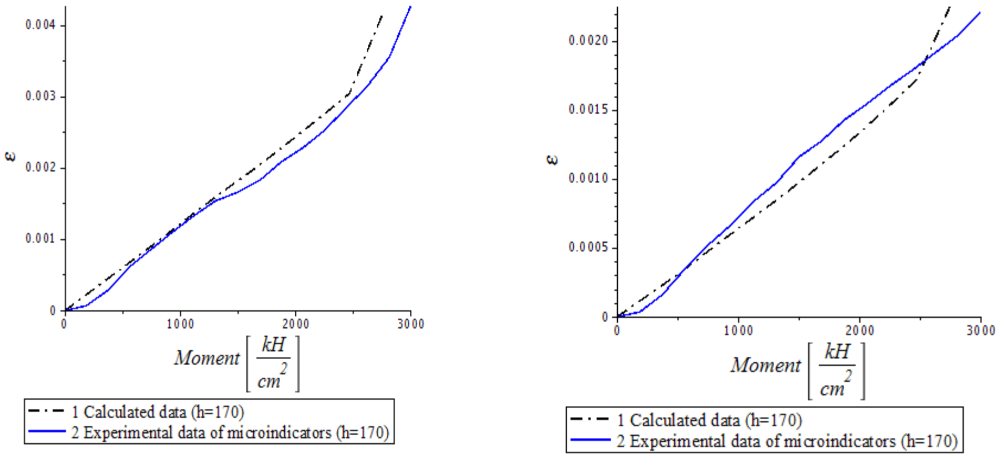


Fig. 6. Diagram of dependence of armature strains on stress in the beam B-2-1-2-0 eg at height (h=170 mm): principal part of the beam, b) – reinforced part of the beam;

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