

## FEATURES OF EXPERIMENTAL STRAIN DETERMINATION OF COMPRESSED-BENT ELEMENTS CONSIDERING THEIR DEFLECTION CURVE

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In this article the methods of experimental acquiring of concrete and reinforcement strains is introduced. The following processing of experimental data is presented.

**Key words:** research, concrete structures, gauges, deformation reduction

Наведено методику експериментального замірювання деформацій верхньої фібри бетону, арматури з приведенням їх надалі для отримання реальних величин деформації.

**Ключові слова:** дослідження, залізобетонні конструкції, мікроіндикатори, індикатори, приведення, деформації

### Problem definition

In experimental studies of the stress-strain state of structures gauges are commonly used. They are used to measure the linear deformation of different materials and can be applied in all spatial positions. Graduations of such devices range from 0.01 to 0.001 mm, which allows to measure the deformation of structures with high accuracy. However, at a specific position of the indicator relative to the structure surface, the measured value of the linear tensile (compression) deformation will differ from the actual. This occurs when the gauges holders are fastened to a surface of the structure which is in process of deformation takes the form of an arch (Fig. 1).

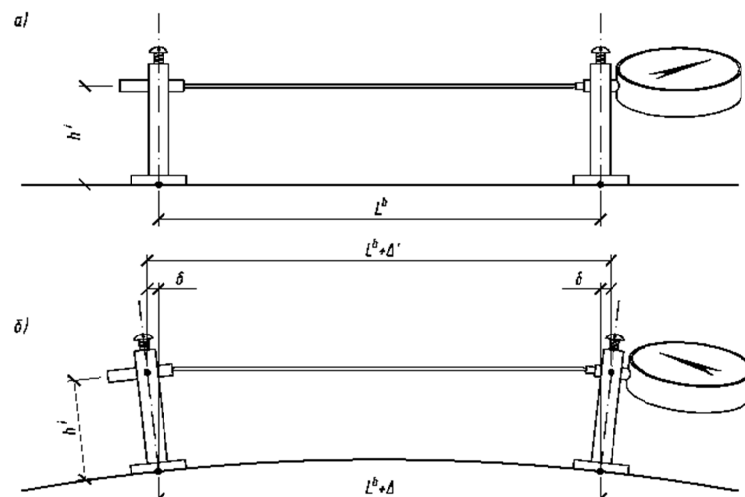


Fig. 1. Gauges position: a – before structure deformation, b – after structure deformation.

Figure 1 uses the following notation:  $L_b$  – original length of measuring device;  $\Delta$  – actual value of linear deformation;  $\Delta' = \Delta + 2\delta$  – measured value of the linear deformation.

As can be seen from Figure 1 the measured value of the linear deformation is different from the actual value for some deviation  $2\delta$ . This deviation appears due to the deflection of the indicator holders. Holders deflection is caused by the deformation of the surface to which they are fastened. Obviously, when processing experimental data acquired from gauges, such deviation must be considered, and therefore it is necessary to develop a method of reduction of the measured values of deformation to the actual ones.

## Analysis of research and publications

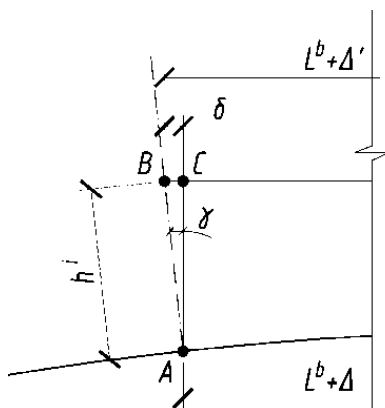
For reinforced concrete beams in [1,2] a method to reduction of linear deformation taking into account the location of the indicator at a certain height relative to the surface of the structure was developed. The basis of this method is the reduction of the deflection curve of the beam beams to the mathematical equation of a circle [3], and then using a graphical approach calculated the actual deviation.

However, the use of method [3] for compressed-bent elements showed somewhat illogical results and proved itself not fitting for such elements. In [4] was an attempt to use a graphical method of reduction based on the true deflection curve of the column. The curve was obtained from 5 deflectometers located along the length of the sample during testing [4]. As a result the deflection curves on each stage of the test were plotted. Then, using a graphical method of reduction, deviation  $\delta$  was calculated (segment BC, Fig. 2) according to a deflection curve for each stage of the test. Such method gives very satisfactory results. However, the graphical method is very time-consuming to apply, especially when the number of devices is significant. Therefore using an analytical approach that would help to automate this process.

**The main purpose.** The purpose of this paper is to develop a method of reduction of linear deformations tension (compression) acquired with deviations to their actual values.

### Mathematical model deformations reduction

For the output data to determine the deviation between the measured and actual values of linear tension (compression) deformations we accept a geometric diagram of indicator holder position after structures deformation (Fig. 2).



*Fig. 2. Geometric diagram of the indicator holder position after structures deformation.*

Deviation  $\delta$  will be determined from the triangle ABC considering following assumptions:

1.  $\delta \ll h^i$ , therefore  $AB = AC = h^i$ ;
2. since the angle  $\gamma$  is very small (in our case not more than  $0.21^\circ$  at midsection and  $2.7^\circ$  at base section), angles at the base of the triangle  $BC$  are approximately equal  $90^\circ$ .

Based on the assumptions above the deviation  $\delta$  can be determined by the following relationship:

$$\delta = h^i \cdot \tan \gamma \quad (1)$$

The indicator holder height  $h^i$  should be measured for every indicator during the test of the structure. The unknown value  $\tan \gamma$  from (1) can be determined from the equation  $y = f(x)$  of the curved axis of the element being tested. Following geometric constructions shall be conducted in plain Cartesian coordinate system  $XoY$  (Fig. 3). Axis  $X$  is chosen along the axis of the element prior to the deformation. Therefore element deflection will occur in the direction of the axis  $Y$ .

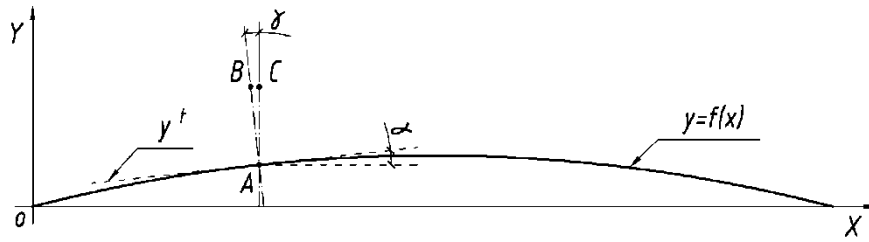


Fig. 3. The curved axis of the elements in the selected coordinate system

We accept that the position of the indicator holder during deformation of the element is perpendicular to the axis of the deflected element. Which means that position of the indicator holder prior to the element deformation is perpendicular to the axis  $X$  of the chosen coordinate system, and after deformation – perpendicular to the tangent  $y'$ . Since segment  $AB$  is perpendicular to  $y'$  and  $AC$  is perpendicular to axis  $X$ , we conclude that the angle of inclination of the tangent  $y'$  in accepted coordinate system is equal to  $\gamma$ . Therefore gradient in the equation of  $y'$  is equal to  $\tan\gamma$ .

Thus we obtain the desired value  $\tan\gamma$  by defining the equation of the tangent  $y'$  to the curved axis of the elements at point  $A$  by the following relationship [5,6]:

$$y' = f(x_A) + f'(x_A)(x - x_A) \quad (2)$$

Where  $x_A$  – coordinate  $X$  of point  $A$  in a given coordinate system;

$f(x_A)$  – the value of the function  $y = f(x)$  at point  $A(x_A; y_A)$ ;

$f'(x_A)$  – the value of the first derivative of the function  $y = f(x)$  at point  $A(x_A; y_A)$ .

The equation of element curved axis is obtained using an approximation of the real graph of the deflection of the element with a curve, such as a parabola.

### Verification of the proposed model

Verification of the proposed method of linear deformities reduction performed on the basis of experimental data obtained from tests of prototype reinforced concrete column. Drawings of the column and its reinforcement scheme presented in Figure 4. Also in Figure 4 the way of fastening the indicator to the reinforcement is illustrated.

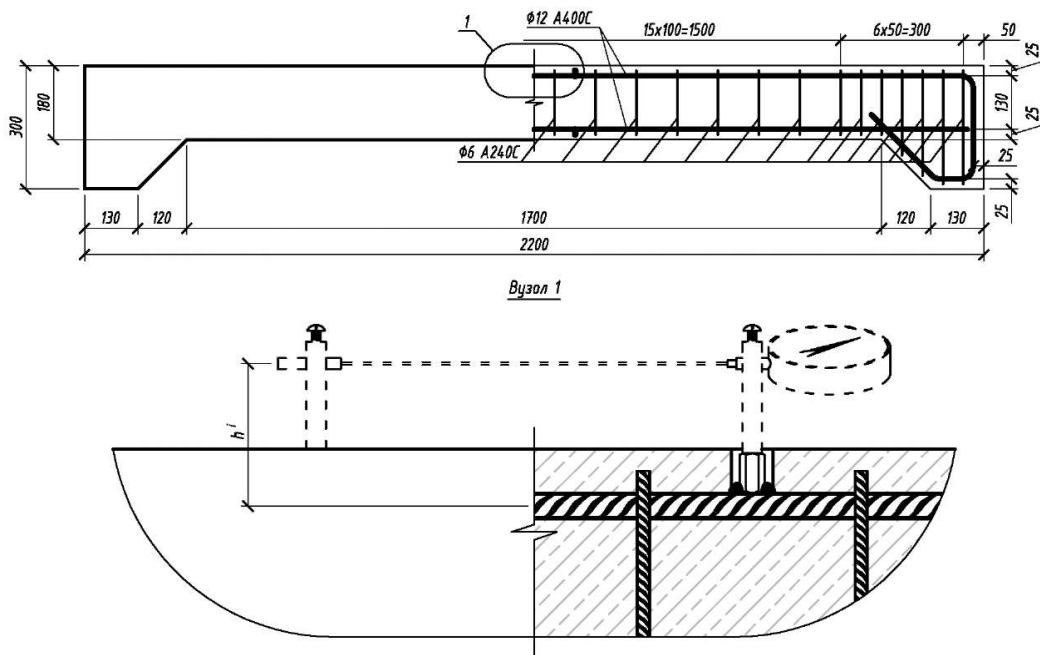


Fig. 4. Drawings of the column prototype and reinforcement scheme

The column loading was applied incrementally, 10 kN at each step maintaining load at each step for 15 minutes. The loading was applied with eccentricity  $e = 150$  mm by the hydraulic jack. The test was conducted in a horizontal position.

To determine the deformation in compressed and stretched reinforcement, compressed concrete, concrete deformations along the height of the column section, gauges with graduations of 0.001 mm were applied. To measure the deflection of the column along its length 5 deflectometers were attached. General view of the column during testing and location of gauges and deflectometers is shown in Fig. 5, 6.



Fig. 5. General view of the experimental setup with the test specimen and the working section

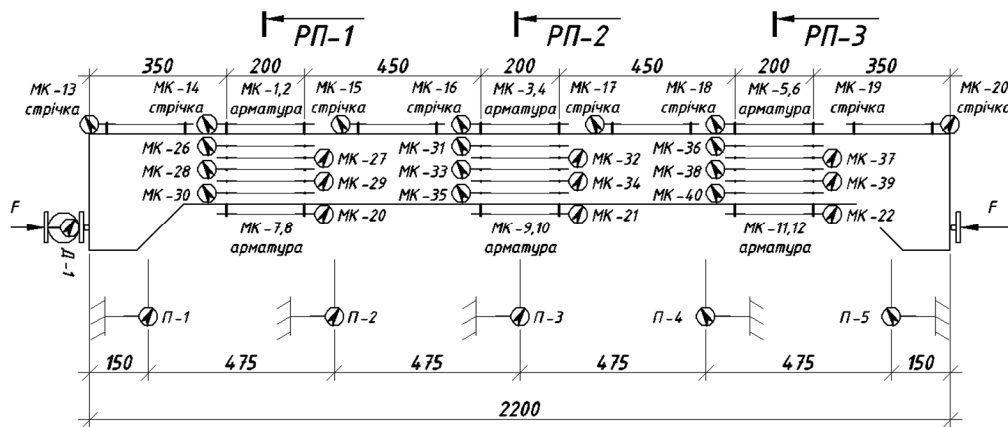


Fig. 6. Location of equipment

According to the data acquired from 5 deflectometers the deflection curves at each loading step were plotted (Fig. 6).

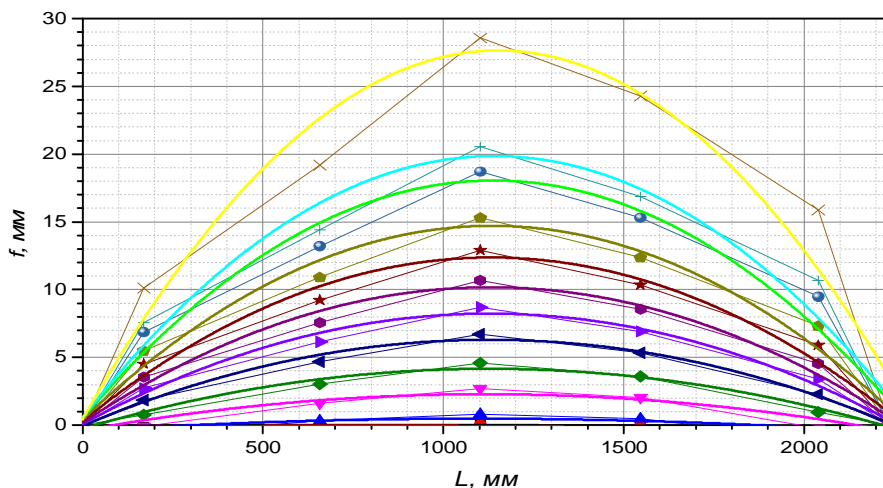


Fig. 6. Deflection  $f$  along the length  $L$  of the column at each step of loading.

To verify the proposed method of deformation reduction the following steps were taken:

1. From the data acquired from gauges the strain of reinforcement at each loading step are calculated. Diagram "load  $N$  – strain  $\varepsilon_{exp}$ " was plotted (Fig. 7a).
2. The reduction of calculated strain was performed. Diagram "load  $N$  – reduced strain  $\varepsilon'_{exp}$ " was plotted (Fig. 7b).
3. According to both diagrams reinforcement strain at yield level  $\varepsilon_{s0,exp}$  and  $\varepsilon'_{s0,exp}$  were determined.
4. Comparison of acquired strain  $\varepsilon_{s0,exp}$  and  $\varepsilon'_{s0,exp}$  from column test with  $\varepsilon_{s0}$  – actual yield strain of reinforcement bars determined during tensile test was conducted.

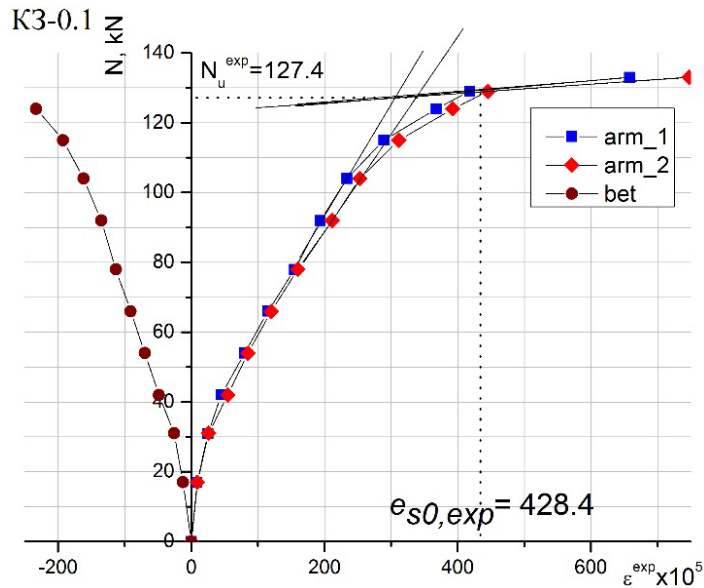


Fig. 7a. Strain of compressed concrete (bet) and stretched reinforcement (arm1, arm2) depending on the load applied to a prototype K3-0.1 before strain reduction

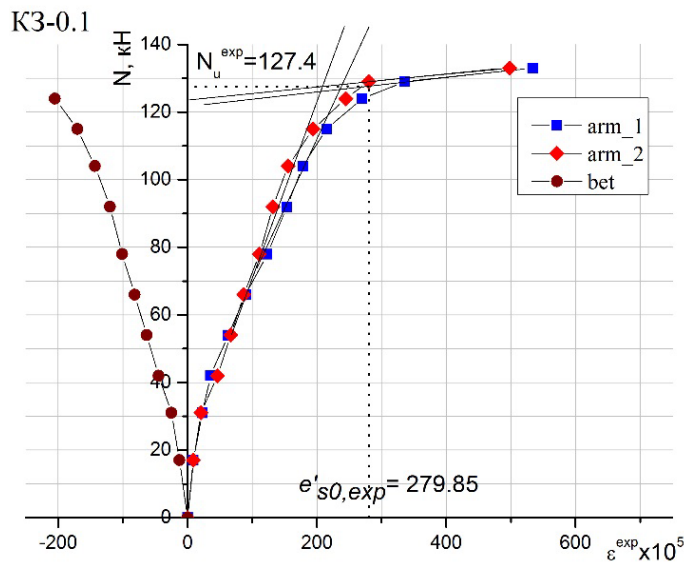


Fig. 7b. Strain of compressed concrete (bet) and stretched reinforcement (arm1, arm2) depending on the load applied to a prototype K3-0.1 after strain reduction

According to both diagrams (Fig. 7a, 7b) reinforcement strain at yield level are following:  
 $\varepsilon_{s0,exp} = 428 \cdot 10^{-5}$  – before reduction;  $\varepsilon'_{s0,exp} = 280 \cdot 10^{-5}$  – after reduction.

Actual yield strain of reinforcement bars determined during tensile test was:  $\varepsilon_{s0} = 285 \cdot 10^{-5}$ . As we can see this value is almost equal to reduced strain  $\varepsilon'_{s0,exp}$ , which means that strain reduction using proposed method give good results. General results of this study are given in Table 1.

Table 1

**Results of strain reduction test data processing, considering its deflection curve**

N, kN	Reinforcement strain before reduction, $\times 10^{-5}$	Reinforcement strain after reduction, $\times 10^{-5}$	Divergence, %	Concrete strain before reduction, $\times 10^{-5}$	Concrete strain after reduction, $\times 10^{-5}$	Divergence, %
31	25.31	10.14	40.1	25.76	19.93	77.4
42	64.52	35.57	55.1	48.48	37.36	77.0
54	98.26	54.51	55.5	69.70	52.87	75.9
66	132.26	73.54	55.6	90.91	68.33	75.2
78	166.75	94.00	56.4	113.13	85.15	75.3
92	201.49	113.66	56.4	113.13	79.34	70.1
104	241.94	136.66	56.5	161.62	121.12	74.9
115	298.76	173.89	58.2	192.42	144.39	75.0
124	378.16	223.71	59.2	232.83	173.42	74.5
129	429.53	258.14	60.1	-	-	-
133	698.76	447.33	64.0	-	-	-

After reinforcement strain reduction their values decreased approximately by 45%. This was due to significant height of indicator holder (45 mm approximately). Gauges for measuring concrete deformations were fastened on holders with the height of 17 mm. That’s why deviation between reduced and not reduced values was approximately 25%. Also it means that strain values also need reduce. Strain reduction method proposed in this article was also applied in other works [8].

**Conclusions**

1. A new method of reduction of deformations measured by dial gauges was developed.
2. After processing the test data of compressed-bent element reinforcement strain was reduced by 45% (indicator holder height 45 mm) and concrete strain reduced by 25% (indicator holder height 17 mm).
3. Reinforcement strain of tested element at yield level after reduction showed almost equal value to actual yield strain of reinforcement bars determined during tensile test.

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