Monitoring of the framings stress-strain with strain gauges

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Abstract. The article describes the research methods of the stress-strain of reinforced concrete framings (piles and pylons) using embedded strain gauges. The relations of load to indirect reactive characteristics displayed by the weighing device which were obtained through laboratory tests of framings reference specimens are given. Summary tables of framings stress-strain monitoring results gained during the II Phase of construction project (after base plate concreting for piles and floor slab concreting for pylons) are included. The study of obtained results of actual framings stress will allow reducing construction material consumption through the reduction of the safety factors on reliability.

1 Introduction

A structural analysis calculation in the design of non-unique structures is based on the experience of construction of similar objects. Yet sufficiently large safety factors on reliability which do not take into account the non-uniformity of structural behavior are set. Measuring of actual piles and pylons stress gives an opportunity to further reduction of framings material consumption when constructing similar objects.

Monitoring of the framings stress-strain is being carried out as a part of the R&D support during the construction of a multi-purpose residential complex with underground parking. The complex consists of two bays with varying number of storeys conjoined with two-level parking space. The constructive scheme of the building is a reinforced concrete cross-wall structure. The foundation is a cast reinforced concrete slab on solid reinforced concrete pre-cast bearing piles of square section measuring 400 × 400 mm (6^{th} segment) and 300 × 300 mm (1^{st} segment).

The TZB-100 and TZB-200 embedded strain gauges for concrete are used for taking of framings stress readings [Fig. 1]. They work as follows: tensile deformation in the thickness of the monitored object increases the distance between strain gauge flanges, and they stretch the rod [Fig. 2]. This stretching is transformed by strain gauge bridge into output (operating factor), which is displayed at the screen of weigh digitizer [Fig. 3] connected to the strain gauge through a power lead. The rod of the strain gauge is covered with plastic film non-adhesive to concrete, therefore shear stresses are not transmitted from concrete to

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the rod, and the strain gauge signal depends only on displacement of flanges, which increases the measurement accuracy. The stiffness of the strain gauge can be adjusted to the stiffness of concrete surrounding it. In this case, the strain gauge does not affect the stress-strain of the controlled object, which significantly increases the reliability of measurements [1-7].

2 Materials and methods

Framings reference specimens were selected in the amount of 4 pieces and strain gauges were installed in them in order to establish a relationship between indirect reactive characteristics displayed by the device and stresses in concrete expressed in kN/sq. cm. As a result of laboratory tests of these specimens the following calibration curves were obtained:

- Geometrical dimensions of the specimen No. 1: 400 × 400 × 600 mm. Type of strain gauge: TZB-200. Concrete design rating: B30.

Table 1. Results obtained from testing of specimen No. 1.

Block step No.	Weigh digitizer readings	Load (kN/sq. cm)*10^(–2)
1	1	0.00
2	1.500	6.25
3	2.578	12.50
4	3.587	18.75
5	4.679	25.00
6	5.824	31.25
7	6.876	37.50
8	8.005	43.75
9	9.113	50.00
10	10.149	56.25
11	11.267	62.50
12	12.324	68.75
13	13.390	75.00
14	14.454	81.25
15	15.593	87.50
16	16.742	93.75
17	17.859	100.00
18	18.937	106.25
19	20.013	112.50
20	21.144	118.75
21	22.286	125.00
22	23.322	131.25
23	24.342	137.50
24	25.418	143.75

25	26.522	150.00
26	27.649	156.25
27	28.656	162.50
28	29.663	168.75
29	30.779	175.00
30	31.915	181.25
31	33.051	187.50

Calibration curve No. 1:

$$Y = 0,0057 \times X - 1.8784 \quad (1)$$

- Geometrical dimensions of the specimen No. 2: 150 × 140 × 600 mm. Type of strain gauge: TZB-200. Concrete design rating: B40.

Table 2. Results obtained from testing of specimen No. 2.

Block step No.	**Weigh digitizer readings**	**Load (kN/sq. cm)*10^(–2)**
	24	0
2	2.730	24
3	5.740	48
4	8.270	71
5	10.824	95
6	13.300	119
7	16.450	143
8	19.200	167
9	21.939	190
10	24.620	214
11	27.322	238

Calibration curve No. 2:

$$Y = 0,0087 \times X - 0,2453 \quad (2)$$

- Geometrical dimensions of the specimen No. 3: 150 × 110 × 300 mm. Type of strain gauge: TZB-100. Concrete design rating: B40.

Table 3. Results obtained from testing of specimen No. 3.

Block step No.	**Weigh digitizer readings**	**Load (kN/sq. cm)*10^(–2)**
1	24	0.00
2	2.800	30.30
3	6.000	71.00
4	8.150	97.00
5	11.250	136.00
6	13.200	160.00
7	14.900	181.82

8	16.700	201.00
9	19.350	234.00
10	21.310	263.00
11	24.012	303.03

Calibration curve No. 3:

$$Y = 0{,}0125 \times X - 4{,}0198 \quad (3)$$

- Geometrical dimensions of the specimen No. 4: 300 × 300 × 600 mm. Type of strain gauge: TZB-200. Concrete design rating: B40.

Table 4. Results obtained from testing of specimen No. 4.

Block step No.	Weigh digitizer readings	Load (kN/sq. cm)*10^(–2)
1	1	0.00
2	450	5.56
3	960	11.11
4	1.457	16.67
5	1.937	22.22
6	2.460	27.78
7	3.025	33.33
8	3.508	38.89
9	4.061	44.44
10	4.551	50.00
11	5.076	55.56
12	5.525	61.11
13	6.090	66.67
14	6.528	72.22
15	7.090	77.78
16	7.539	83.33
17	8.015	88.89
18	8.500	94.44
19	9.004	100.00
20	9.502	105.56
21	10.050	111.11
22	11.077	122.22
23	12.189	133.33
24	13.272	144.44
25	14.428	155.56
26	15.579	166.67
27	16.687	177.78
28	17.702	188.89

29	18.737	200.00
30	19.798	211.11
31	20.904	222.22

Calibration curve No. 4:

$$Y = 0.0106 \times X – 2.1011 \quad (4)$$

Then the strain gauges are being installed directly into the framings of residential complex: after pile sinking a hole with a diameter of 80 mm and a depth of 400 mm was drilled by means of boring tool on the surface of each pile. Then the strain gauge was installed there. The holes with strain gauges were grouted using the concrete repair mortar with project age strength equal to 100 % of pile concrete design rating (400 × 400 mm — B30; 300 × 300 mm — B40). Pylon strain gauges were installed before the mounting of cheek boards in the place where they are jointed with the base plate. Before being cased each device was fixed with wires to the reinforcement in an intended orientation [8-15].

Stress monitoring is carried out in 6 stages:

1. After framings concrete is hard, the initial values are documented,
2. After concreting of the base plate for the piles and the floor slab for the pylons,
3. After the construction of the underground part of the building,
4. After the construction of 50 % of superstructure concrete components,
5. After the construction of 50 % of superstructure concrete components,
6. After the construction of interior walls and partitions, facades (when structural works at the monitored segment are completed).

3 Results and discussion

Documented indirect reactive characteristics readings of the strain gauge are summarized in the table. This table includes stress occurring in the framings as a result of imposed load which were calculated from the obtained calibration curves for different types of framings and concrete grades, as well as the excess of indirect characteristics in relation to previous load step.

Table 5. Results of the piles stresses monitoring (phase II).

Segment No.	Segment 1				Segment 6			
Type of structural element and its basic characteristics (size of the section, concrete grade)	Pile 300 × 300, B40	Pile 300 × 300, B40	Pile 300 × 300, B40	Pile 300 × 300, B40	Pile 400 × 400, B30	Pile 400 × 400, B30	Pile 400 × 400, B30	Pile 400 × 400, B30
Type of strain gauge	TZB-200	TZB-200	TZB-200	TZB-200	TZB-200	TZB-200	TZB-200	TZB-200
“Zero” values – Initial values (when hardening of concrete repair mortar is completed)								
Recorded readings, indirect reactive characteristics of strain gauge	–3.200	–1.980	–1.102	–1.688	–2.800	–3.274	–2.478	1.124

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Excess of indirect characteristics in relation to previous load step	0	0	0	0	0	0	0	0
Stresses occurring in the framings as a result of imposed load, calculated from calibration curve, kN/sq.cm *10^(–2)	0	0	0	0	0	0	0	0
Phase I – After concreting of the base plate								
Recorded readings, indirect reactive characteristics of strain gauge	1.457	–2.406	420	386	–2.891	–2.322	–3.020	–2.422
Excess of indirect characteristics in relation to previous load step	4.677	–426	1.522	2.074	–91	952	–542	–3.546
Stresses occurring in the framings as a result of imposed load. calculated from calibration curve, kN/sq.cm *10^(–2)	51.68	–2.41	18.23	24.09	–2.4	3.55	–4.97	–22.09
Phase II – After the construction of the underground part of the building								
Recorded readings, indirect reactive characteristics of strain gauge	–3.158	–2.926	–392	–2.360	–3.125	–2.236	11.916	–4.106
Excess of indirect characteristics in relation to previous load step	–4615	–520	–812	–2746	–234	–234	86	14.936
Stresses occurring in the framings as a result of imposed load, calculated from calibration curve, kN/sq.cm *10^(–2)	–46.82	–3.41	–6.51	–27.01	–3.21	–1.39	83.26	–11.48

Table 6. Results of the pylons stresses monitoring (phase II).

Segment No.	Segment 6							
Type of structural element and its basic characteristics (size of the section. concrete grade)	Pylon, B40			Pylon, B40			Pylon, B40	
	1	2	3	1	2	3	1	2
Type of strain gauge	TZB-200	TZB-200	TZB-200	TZB-100	TZB-100	TZB-100	TZB-200	TZB-200
"Zero" values – Initial values (when hardening of concrete repair mortar is completed)								

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Recorded readings, indirect reactive characteristics of strain gauge	–831	–162	–2.061	–375	–506	–490	9	–532
Excess of indirect characteristics in relation to previous load step	0	0	0	0	0	0	0	0
Stresses occurring in the framings as a result of imposed load, calculated from calibration curve, kN/sq. cm*10^(–2)	0	0	0	0	0	0	0	0
Phase I – After concreting of the floor slab (-1 level)								
Recorded readings, indirect reactive characteristics of strain gauge	–1.423	–1.010	–1.450	1.238	–230	217	348	128
Excess of indirect characteristics in relation to previous load step	–592	–848	611	1.613	276	707	339	660
Stresses occurring in the framings as a result of imposed load, calculated from calibration curve, kN/sq. cm*10^(–2)	–5.4	–7.62	5.07	6.14	–0.57	4.82	2.7	5.5
Phase II – After the construction of the underground part of the building								
Recorded readings, indirect reactive characteristics of strain gauge	16.722	5.468	–1.247	2.921	85	1.110	767	1.244
Excess of indirect characteristics in relation to previous load step	18.145	6.478	203	1.683	315	893	419	1.116
Stresses occurring in the framings as a result of imposed load. calculated from calibration curve, kN/sq. cm*10^(–2)	18.145	6.478	203	1.683	315	893	419	1.116

4 Conclusion

The R&D support of the construction and monitoring of the object, as well as subsequent studies of obtained data, will allow project designer to estimate the differences between project and actual values of stresses. During the subsequent project installation engineers will be able to make changes to the calculation of the building frame. The reduction of the framings cross section will significantly reduce the cost of construction.

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