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 (6th segment) and 300 × 300 mm (1st 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                 |
| Block step No. | Weigh digitizer readings | Load (kN/sq. cm)*10^(–2) |
|---------------|--------------------------|--------------------------|
| 1             | 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. 1:

\[ Y = 0.0057 \times X - 1.8784 \]  \hspace{1cm} (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) |
|---------------|--------------------------|--------------------------|
| 1             | 24                       | 0                        |
| 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                   |

Calibration curve No. 2:

\[ Y = 0.0087 \times X - 0.2453 \]  \hspace{1cm} (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.
Calibration curve No. 3:

\[ Y = 0.0125 \times X - 4.0198 \]  

(3)

- Geometrical dimensions of the specimen No. 4: 300 × 300 × 600 mm. Type of strain gauge: TZB-200. Concrete design rating: В40.

**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                   |
Calibration curve No. 4:

\[ Y = 0.0106 \times X - 2.1011 \]  \hspace{1cm} (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 \times 400 \text{ mm} — B30; 300 \times 300 \text{ 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 \times 300, B40 | Pile 300 \times 300, B40 | Pile 300 \times 300, B40 |
| | Pile 300 \times 300, B40 | Pile 400 \times 400, B30 | Pile 400 \times 400, B30 |
| | Pile 400 \times 400, B30 | Pile 400 \times 400, B30 | Pile 400 \times 400, B30 |
| Type of strain gauge | TZB-200 | 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) | –3.200 | –1.980 | –1.102 |
| Recorded readings, indirect reactive characteristics of strain gauge | –1.688 | –2.800 | –3.274 |
| | –2.478 | 1.124 | |

5
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)
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)**

|                      | -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**

|                      | 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.
References

1. S. Sinenko, T. Poznakhirko, MATEC Web of Conferences 193, 05011 (2018)
2. M. Rogalska, Z. Hejducki, Journal of Civil Engineering and Management 5, 7858 (2005)
3. D. Topchiy, A. Tokarskiy, IOP Conference Series: Materials Science and Engineering 365, 062005 (2018) https://doi:10.1088/1757-899X/365/6/062005
4. W. Bożejko, Z. Hejducki, M. Uchroński, M. Wodecki, Journal of Civil Engineering and Management 20 (2014) DOI: 10.3846/13923730.2014.906496
5. P. Oleinik, A. Yurgaytis, MATEC Web of Conferences 117, 00130 (2017) https://doi.org/10.1051/matecconf/201711700130
6. D. Topchiy, A. Shatrova, A. Yurgaytis, MATEC Web of Conferences 193, 05032 (2018) https://doi.org/10.1051/matecconf/201819305032
7. D. Topchiy, E. Kochurina, MATEC Web of Conferences 193, 05012 (2018) https://doi.org/10.1051/matecconf/201819305012
8. P. Oleinik, A. Yurgaytis, MATEC Web of Conferences 117, 00130 (2017) https://doi.org/10.1051/matecconf/201711700130
9. W. Bożejko, A. Gnatowski, J. Pempera, M. Wodecki, Computers & Industrial Engineering 113, 512-524 (2017)
10. W. Bożejko, J. Pempera, M. Wodecki, Archives of Control Sciences 27(2), 169-181 (2017)
11. F. Berrah, F. Boursas, S. Bouacida, F. Ouannassi, Journal of Molecular Structure 12055, 127624 (2020)
12. S. Madhan Kumar, P. Muthuraja, M. Dhandapani, Journal of Molecular Structure 11975, 19-33 (2019)
13. Y. Li, H. Wang, W. Cai, Sh. Li, Q. Zhang, Measurement 1531, 107449 (2020)
14. H. Zhang, Sh. Hou, J. Ou, Engineering Structures 1901, 66-75 (2019)