Tenzometric method implementation for determining SSS in combined grillages

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Abstract. The article presents an analysis of the tensometric method for determining the stress-strain state of the combined grillages. The technical condition and reliability degree of the structural elements are analyzed, the values of the soil anchors’ tension are obtained and compared, the dependence of the anchors’ tension, stresses in concrete and groundwater back pressure is analyzed.

Introduction
Construction in the southern regions of the Crimean Peninsula entails the important tasks’ solution to ensure the reliable and durable operation, supporting structures of buildings and structures in difficult engineering-geological and geophysical conditions. Landslide, tectonic and seismic processes are widely developed at the construction sites, leading to geological environment’s instability. The wide use in these engineering-geological and geophysical conditions has received the combined grillages’ project designed to hold the landslide loads.

Subject of study this work is a tensometric method for determining the stress-strain state in load-bearing structures.

Object of study – combined grillages.

The purpose and objectives of the research
Purpose of the study is the tensometric method implementation for determining SSS in combined grillages, during the technical inspection at the facility: “Recreation complex at Republic of Crimea, Alupka”, establishing the combined grillages’ structural elements actual technical condition with an assessment of the operational reliability degree and compliance requirements of modern standards for the buildings and structures design in an earthquake-prone area.

The research objectives:
1. To measure the tension of the soil anchors and compare it with the previously fixed values.
2. To use the tensometric method to establish the stresses value in concrete in the most loaded structures’ sections.
3. To assess the main structural elements’ technical condition.
4. To substantiate the reliability degree of the structural elements and grillages in general.
5. To analyze the dependence of the anchors’ tension on the stresses in the concrete and the pressure of the ground backwater.

The main section with the results and their analysis
Initial information about the object
The construction site is located in a mobile exo- and endo-dynamic zone, subjected to constant relatively accelerated geo-medium development, due to the influence of such powerful factors of geological, geomorphological (relief) and geotechnical instability as: landslide processes, seismicity, tectonic activity, anthropogenic (technogenic) impact.

Design seismicity - 8 points. Soil seismic properties belong to the category II.

Space-planning and structural solutions
The combined grillage is a part of a retaining structures’ complex located on a landslide site. A landslide load with a design vertical layout is 181.8 t / m. The estimated soil pressure on the combined grillage with a height up to 20.3 m is 176.1 t / m. The combined grillage consists of a number of piles Φ1,02 m with a step of 2.2 m, an anchor wall, monolithic cladding plates, monolithic clamping plates with prestressed drill injection anchors from the six strands of K-7 rope from 14 to 27 m long, an anchor pitch of 2.2 m (the calculated anchor tension force is 80,1 t).

Investigation methodology
The facility inspection of was carried out in accordance with the regulatory documents and special literature [1-4] in accordance with the following general plan:
- the design documentation study and visual examination;
- development of a plan for instrumental examination and verification of the survey results’ reliability;
- the structures’ instrumental examination;
- statistical processing of the structural parameters control results [3].

The experimental determination of stresses arising in grillages is based on the deformations’ determination by the electro-tensometric methods, namely, the “stress relieving” method.

The method for determining residual stresses by relieving stresses of a material column and simultaneously registering deformation of the column surface is based on the fact that the residual stresses are the volumetric stresses, i.e. the sources of these stresses are located at all points of the structure’s body volume. The fields of these stresses are balanced over the entire volume of the structure and, therefore, cutting out a certain volume of the material frees this volume only from the rest of the structure acting on it. A part of the stresses remains in the cut-out volume and is balanced inside it. To determine the true value of this kind residual stresses, at some point a material column was cut from the volume of the entire structure, the dimensions of which were determined mainly by the dimensions of the resistance strain gauges placed on it, and the height was not less than half of the column’s larger side (Figure 1).

Figure 1. Residual stress measurement scheme:
Concrete deformations on the front surface of the grillage structures (pressure plates) were determined using loopback wire resistance strain gauges on a paper basis with a base length of 50 mm and a nominal resistance of 400 Ohm. This type sensors’ use validity is explained by the possibility of the strains’ direct registration on the surface of the structure with high accuracy of strain measurements.

Survey Findings
The condition of all structural elements is limitedly operable, but there are shrinkage and force cracks. To confirm the operability and stability of the combined grillage, it is necessary to determine the soil anchors’ tension level and compare it with the previously obtained values, as well as to find out the value of stresses in concrete in the most loaded areas.

The results of determining the tension force of the soil anchor
In October 2016, the measurements were made on the soil anchors’ tension forces. Figure 2, 3, 4 show the graphs of changes in the magnitude of the anchors’ tension.

Figure 2. Schedule of change in the magnitude of anchor tension force 1.11 cr.5.1

Figure 3. Schedule of change in the magnitude of anchor tension force 1.13 cr.5.2

Figure 4. Chart of change in the magnitude of anchor tension force 1.11 cr.5.3

The graphs show that for the period from 2011 to 2016, the efforts in the anchors decreased by an average of 200 kN. In 2016, the efforts in the tested anchors increased by an average of 100 kN. The change in the force in the anchors is associated with a change in the strength and deformation characteristics of the backfill soil. As the groundwater level rises, the strength of the backfill soil decreases, and the grillage wall shifts toward the backfill, and the tension force of the ground anchors decreases. Conversely, when the groundwater level decreases, the strength of the backfill soil increases and the ground anchors’ tension force increases.

The choice of places for determining stresses in concrete
Before proceeding to the stresses’ determination in concrete, it is necessary to indirectly analyze the combined grillages’ stress-strain state. According to the provisions of building mechanics with a uniformly distributed load of cantilever elements, maximum internal forces arise in pinching. Since the combined grillages are pinched in the ground and reinforced with soil anchors (a complex stress-strain state), the most stressful places were selected according to the internal forces’ isofields obtained.
by calculating a fragment of the finite element model in the Lira-CAD-2016 software package (Figure 7.8).

The initial data:
1. The calculated soil pressure on the combined grillage with a height of up to 16.2 m is 162.0 t / m.
2. Rigidity of elements (Table 1.).

Conclusion according to the calculation results: maximum stress places occur in the first and second tier of the pressure plates.

Table 1. Rigidity of elements

| Stiffness type | Name                        | Parameters  |
|----------------|-----------------------------|-------------|
|                |                             | (cross-section- (cm) stiffness- (t, m) distribution weight- (t, m)) |               |
| 1              | Ring 102 X 0 (Pile)         | Ro=2.75,E=3e+006,GF=0 |
|                |                             | D=102,d=0   |
|                |                             | EF=2.45138e+006,ElY=159401 |
|                |                             | ElZ=1.59e+005,GIk=1.3e+005 |
|                |                             | Y1=5.4e-010,Y2=5.4e-010,Z1=0,Z2=0 |
| 2              | Beam120 X 100 (Grillage)    | Ro=2.75,E=3e+006,GF=0, B=120,H=100 |
|                |                             | EF=3.6e+006,ElY=300000 |
|                |                             | ElZ=4.32e+005,GIk=2.47e+005 |
|                |                             | Y1=1.34e-008,Y2=3.1e-009,Z1=5.28e+013,Z2=0 |
| 3              | Plate H 50 (PP)             | E=3e+006,V=0.2,H=50,Ro=2.75 |
| 4              | Plate H 20 (OP)             | E=3e+006,V=0.2,H=20,Ro=2.75 |
| 5              | Plate H 40 (AC)             | E=3e+006,V=0.2,H=40,Ro=2.75 |
| 6              | Rope 44.0 (Ground Anchor)   | q=0.00678089 |
|                |                             | EF=12953.6,ElY=0.013 |
|                |                             | ElZ=0.013,GIk=0  |
| 7              | Beam 40 X 40 (Fictitious)   | Ro=0.001,E=3e+006,GF=0 |
|                |                             | B=40,H=40, EF=480000,ElY=6400 |
|                |                             | ElZ=6.4e+003,GIk=4.3e+003 |
|                |                             | Y1=2.79e-012,Y2=2.79e-012,Z1=3.44e+010,Z2=0 |
**Figure 5.** The calculated course-element model of the combined grillage fragment

**Figure 6.** Volume model of the combined grillage fragment

**Figure 7.** Mosaic of horizontal stresses in the elements of pressure plates, cladding slabs and anchor walls
Figure 8. Mosaic of vertical stresses in the elements of pressure plates, cladding slabs and anchor walls

The results of the stresses’ determination in concrete

On the examined combined grillage, 6 mini-sockets from the resistance strain gauges with bases of 50 mm each were installed. The counts from the resistance strain gauges were taken before and after the cross-section’s weakening. Relative concrete deformations were calculated from the measurements. To calculate the stress degree in concrete from the obtained relative deformations, it is necessary to know the class of concrete, the elastic modulus of concrete, and the ultimate relative deformations of concrete. To do this, the concrete cylinders with a diameter of 70 mm and a height of 280 mm were drilled and prepared from a combined grillage, and the necessary characteristics of concrete were determined in laboratory conditions according to GOST 24452-80 [2]:
- concrete compressive strength B25;
- heavy concrete, medium density 2260-2350 kg/m³;
- concrete elasticity modulus Е=240000 kgf/cm²;
- ultimate relative compressive strain of concrete ε₀=0.0021.

Table 2. The results of the stresses’ determination in concrete

| Snapping a place to determine the stress in concrete | Stress in concrete in kgf/cm² ("-" - compression; "+" - stretching) | Standard concrete resistance to axial compression strength in kgf/cm² | Standard concrete resistance to axial tensile strength in kgf/cm² |
|---------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| Between anchors 4.4-4.5 | -58.08 | -185 | +15.5 |
| Near the anchor 4.7 | -29.43 | -185 | +15.5 |
| Near the anchor 4.13 | -64.04 | -185 | +15.5 |
| Near the anchor 4.18 | -55.74 | -185 | +15.5 |
According to the data presented in Table 2, it is possible to conclude that at the time of the examination, the stress-strain state of the combined grillage in places of the soil anchors’ design location is characterized by “compression”, and the main compressive stresses do not exceed the standard concrete resistance in axial compression strength.

### The results of the stresses dependence analysis in concrete, tension forces of anchors and groundwater upthrust

Since the strain gauge mini-sockets were installed on the combined grillages (fast. 5.1, fast. 5.2, fast. 5.3) not near the tested soil anchors, according to the test results, it is possible to tentatively assume the dependence of stresses in concrete on the anchors’ tensile forces and groundwater back pressure, taking the anchors’ tension efforts the same as in the stress determination areas in concrete (see Figure 9).

**Table 3. The results of the stresses’ determination in concrete**

| Snapping a place to determine the stress in concrete | Stress in concrete in kgf/cm$^2$ (“-” - compression; “+” - stretching) | Snapping a place to determine the tension force of the soil anchor | Ground anchor tension force in kN |
|----------------------------------------------------|-------------------------------------------------------------------|-----------------------------------------------------------------|---------------------------------|
| fast. 5.1 between anchors 1.4–1.5 and 2.4–2.5      | -90.04                                                             | fast. 5.1 anchor 1.11                                           | 407                             |
| fast. 5.2 near the anchor 3.17                      | -34.66                                                             | fast. 5.2 anchor 1.13                                           | 675                             |
| fast. 5.3 near the anchor 4.13                      | -65.33                                                             | fast. 5.3 anchor 1.11                                           | 537                             |

Based on the available test data and using a polynomial of degree 6, a trend line is built.

**Figure 9. Estimated dependence of stresses in concrete from the anchors’ tension**

The analysis of the constructed dependence shows that when the tension force in the anchors drops, the compressive stresses in concrete reach 160 kgf/cm$^2$, which do not exceed the standard resistance of concrete in axial compression strength of 185 kgf/cm$^2$. With an increase in the tension force above the calculated...
anchor tension force of 801 kN, the fiber stresses in the extreme fibers of the grillage will develop from compressive to tensile, creating the conditions for the onset of the concrete microcracking and cracking.

**Summary**

1. Landslide, tectonic and seismic processes are widely developed at the construction site, leading to the geological environment’s instability.

2. The condition of all structural elements is limitedly operable, but there are shrinkage and force cracks. Shrinkage cracks appear in the places of expansion joints, which is natural. Power cracks appear in tiles that are not reinforced with soil anchors.

3. During the period from 2011 to 2016, the efforts in the tested anchors decreased by 200 kN. For 2016, the efforts in anchors increased by 100 kN. The change in the force in the anchors is associated with a change in the strength and deformation characteristics of the backfill soil. When the groundwater level rises, the strength of the backfill soil decreases, and the grillage wall shifts toward the backfill, and the tension force of the ground anchors decreases, and vice versa, when the groundwater level decreases, the backfill soil strength increases and the tension force of the ground anchors increases.

4. The stress-strain state of the combined grillage in the places of the soil anchors’ design location is characterized by the “compression” state, and the main compressive stresses do not exceed the standard resistance of concrete in axial compression strength.

5. The constructed dependence of stresses in concrete, tensile forces of anchors and groundwater abatement can be used for repeated measurements.

**References**

[1] GOST 31937-2011. Buildings and structures. Rules for surveying and monitoring the technical condition (Moscow, StandardInform) 2011.

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[3] Postman G Y, Yakovlev A I 1973 Methods and means of testing construction structures (tensoresistive, acoustic and with the help of ionizing radiation) (Moscow, High School) 160.

[4] Designing retaining walls and basement walls. Reference to SNIP 2.09.03-85 (Moscow, CNIIProms, Construction) 1990.