Methods for automatic monitoring construction of earthworks (embankments, retaining walls, construction of reinforced soil) erected in complicated geotechnical conditions.

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Abstract

Automatic monitoring systems currently provide great opportunities for measuring and they are a source of very valuable information for the designers, contractors and investors. Very popular in Poland to conduct investments in mode *"design and build"* requires very careful optimization of design and applied technology application to keep up with the economic assumptions and time quality requirements set by the Investor. Proper selection of geotechnical monitoring system often allows for very effective conduct various stages of construction, optimal use of time. This article discusses various solutions for monitoring earth structures, including reinforced geosynthetics, their capabilities and benefits posed by their use in the investment process and ensure safety during use stage.

Inroduction

At a time when public safety is a top priority, monitoring of building structures becomes more than ten years ago an integral part of construction projects. In Europe and in the world monitoring became popular thanks to projects carried out by observation, which allow European standards (including EC7 [1]). Whereas in Poland it has gained particular importance since the construction disaster in the International Exhibition in Katowice, when 28.01.2006r. during the exhibition the roof has collapsed, resulting in 65 people died and more than 170 were injured. Since then, there are also national regulations and standards talking about the need for constant monitoring of the parameters relevant to the safety design for public buildings where it can remain a considerable number of people. The need for monitoring the structural forces sometimes also in modern architecture, where new buildings characterized by an innovative design, increasing span and complex shape. Monitoring in such cases allows assessing not only the work of construction, early warning of damages, prevention of the damages of the structures but also ultimately improve the safety of users.

Very popular is also the lead investment mode "design & build", where great importance is given to the optimization of investments, which must ensure the economic assumptions, whilst complying with the requirements of quality and time. Morover, the additional advantage is the ability to verify design assumptions on operational stage, especially during the warranty period. In this type of investments the right choice of monitoring allows the effective conduct construction, optimal use of technology and time.

The monitoring system should be treated as a tool to improve the quality and reduce the cost of warranty service project. First of all, you can:
- Control of time and the course of the various stages of construction;
- Quality control of supplied materials and work contractors;
- Control of the state objects within the warranty period (the possibility of early intervention);
- Obtain documentation for any disputes and misunderstandings;
- Obtaining information for resolving disputes warranty.

Information provided by the monitoring system allow to:
- Increase the quality of work, we get a "product" of better quality;
- Time management, to provide time for the needs of the technological regime;
- Control of quality of work, often out of reach;
- Support acceptance procedures, verification of work during the warranty period;
- Source documentation for any disputes warranty;
- Verification of design assumptions;
- The ability to manage risk.

More often automated monitoring systems are used in geotechnical engineering. They are the most commonly applied in areas such as:

a) Control of stability of embankments:
  - Measurements of vertical and horizontal displacements of the embankment;
  - Control deformation of geosynthetic materials;
  - Creep control at the base of the embankment,

b) Monitoring settlement of embankments:
  - Measurements of subsidence at selected points;
  - Determining profiles of subsidence and horizontal displacement of soil,

c) Monitoring consolidation process:
  - Measurement of subsidence;
  - Measurement of the lateral displacement of the soil;
  - Measurement of pore pressure;

d) Control reinforced areas eg. by piles or GEC:
  - Monitoring of the reinforcement over the piles;
  - Consolidation of columns and the ground between them;
  - Measurement of the pressure on the column and the ground between the columns.

e) Control of the reinforced abutments, retaining walls and other retaining structures;

f) Monitoring of the areas of active mining, monitoring continuous and discontinuous deformation zones.

The rest of this article will discuss four investment, where due to the complicated geotechnical conditions decided to use the automated monitoring systems.

Motorway A-1, Maciejow – Piekary Slaskie

Motorway A-1, Maciejow – Piekary Slaskie was builded in 2010-2012. High tensile strength geosynthetic reinforcements coupled with two monitoring systems will protect several sections of Al Motorway in Poland located in heavy active mining terrain. The construction works of two main sections of Al motorway in Poland: Pyrzowice - Piekary Slaskie - Maciejow have started in 2010. This highway is a part of Trans-European Transportation Corridor TEN-T in direction north-south, connecting Baltic Countries with the South of the Europe. Some parts of this road located in the Silesia Region are endangered by active mining and post mining risks, due to actual and historical coal, plum and zincores excavations. There are occurred in the terrain with many large forms of mining deformations and with a different geometry and sizes, like: sinkholes, gaps, faults or steps and very deep subsidence damages. The terrain is also strongly affected by historical mining too, which has started in XVIII century.

The contractors of the building works were confronted with the need of designing and installing the automatic monitoring system, which will meet the following requirements:
- Monitored area: app. 100 000 m2

- The durability of measuring elements: minimum 30 years

An independent measurements of vertical ground displacements (uncovering the places of the deformation occurrence) and of the geogrid strain. [3].

The designed and completed monitoring system consists, physically, of two independent measuring systems collecting data separately. These data are then processed parallel by their analytical processes and in the final phase can be mutually supplemented in order to provide the full information of the existing situation. Two subsystems are:

- monitoring of the vertical displacement of the ground - uncovering of the deformation place;
- monitoring of the horizontal displacements - monitoring of the reinforcing geogrid strain.

Both measuring systems are performing readouts at the same time. Only the simultaneous readouts allow for the analysis of the influence of the vertical ground displacements on the horizontal geogrid strains and their propagation.

The implemented monitoring system is for sure one of the largest and the most innovative on the international experiments scale. It can be stated, even today, when the range of available data will enable more accurate recognition and verification of the geotechnical problems as well as the surface protection against mining damage influences [Fig. 1]. It will certainly broaden the Polish and world science in the scope of utilising grounds reinforced by geosynthetics in zones endangered by mining damages. The implemented monitoring system will turn out helpful in a social measure measurements of the safety improvement processes and in the administration effectiveness of highways passing via zones of difficult ground conditions.

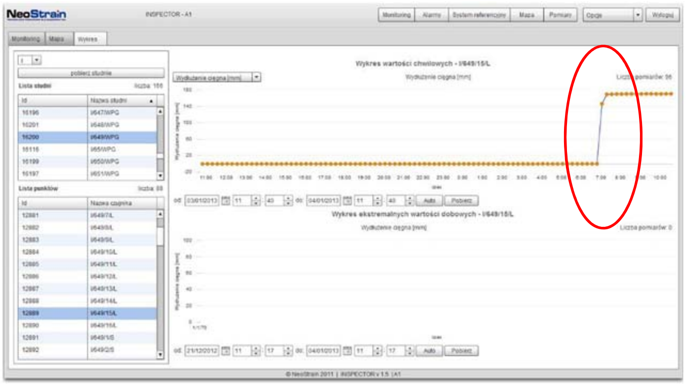

Fig.1 The cavity on the slope (junction „Piekary”) in 2013 and wireless possibility to recording events.

Motorway A-2, Lagow – Jordanowo

This part of Motorway A-2 was builded in 2010. There was first professional application of GEC in Poland occurred in 2010-2011 during the construction of the Highway A2 (between km 60+220 and km 60+450). In this section the A2 crosses an area of very low-bearing organic soils with the thickness up to 28 m [Fig. 2]. A very detailed design and comprehensive monitoring of all construction stages ensured all requirements defined by Client concerning the allowable postconstruction settlements, (10 cm) and the allowable long term settlement difference (15 mm/10 m) during 30 years under operation, could be achieved.

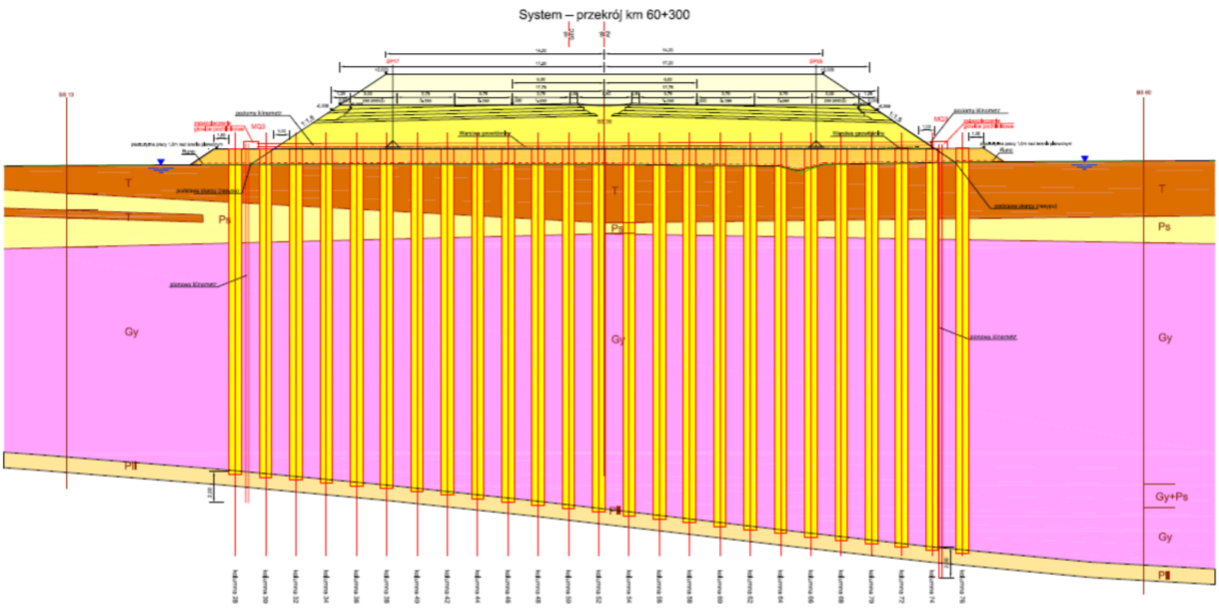

Fig 2. Cross-section through the structure [4]

The key points of the constructed foundation system are presented below:
-number of columns: 3400
-soil exchange ratio: 15 %
-maximum column length 28 m.
After installation of the columns, a sand leveling layer with a thickness of 30 cm was placed and the basal reinforcement (Stabilenka@ 800/100) was installed. In this period many monitoring devices were assembled or attached to geotextiles. After installation all of the monitoring devices the first base measurements readings were made.

There was designed a comprehensive geotectechnical measuring program to verify the property of assumptions which were made in the static calculations and in the achieved results of the final design. Finally, the results of the monitoring were decisive for the removal of the preload. The measurements are scheduled to continue for five years after the highway operation was started.
The monitoring system were consist of:
-29 bench marks with telescopic connected pipes,
-6 hydrostatic lines for settlement measurements (3 in the longitudinal direction and 3 in the crosswise direction, Lhotzky system),
-4 sensors for measurements of vertical stresses on column heads and between columns,
-4 columns with installed sensors for measurements of column perimeter,
-10 vertical inclinometer pipes installed at the embankment toe for the observation of the spreading behavior of the embankment base and deeper subsoil.
The method of the hydrostatic profiles used for settlement measurements was developed by the German Company Lhotzky.

Based on a detailed design and an extensive monitoring it was possible to give the proof, that the designed and executed GEC for this embankment fulfills design and functional assumptions.

Express Road S-19 Dabrowica – Konopnica

This part of Express road S-19 was built in 2015 – 2016. Unfavorable ground conditions and terrain (large local slope) required a huge amount of earthworks, which directly affect the time and costs of the investment. The designer of S19 expressway Lubartów Kraśnik in the section from the Dąbrowica (without the junction) to the node Konopnica (including the hub) decided to strengthen the subsoil by using columns, maintaining unfavorable terrain shape and performing them small terraces for working platforms. The contractor was obligated to perform the automatic monitoring of ground and embankment in terms of slip during the construction period, and then continue it for 10 years in 20 sections on total length of 365 m.

The system was based on measurements of horizontal displacements of the embankment construction in two integrated subsystems. The first one consisted of 24 vertical inclinometers (ie. chain inclinometer) IPI type to a depth of 10m or 11m. The second one, designed to measure horizontal displacement was base on special tension strings which were combined with the measuring sensors Geokon 4450. These sensors measure the tensile elongation of the strings.

Accordance to the specifications, the measuring devices were installed in 24 measuring sections. At one of the edge of each section (measuring points) installed measuring devices recording horizontal displacements in the cross-section. The measuring equipment was installed in a rack mounted on the concrete protective enclosure. Between the measuring points were made teletechnical path for supplying power to each point and collect data for one measuring point. The typical cross-section of the measurement is shown graphically on the figure below [Fig. 3]. Positions and the location of measurement points are shown graphically in Figure 4.

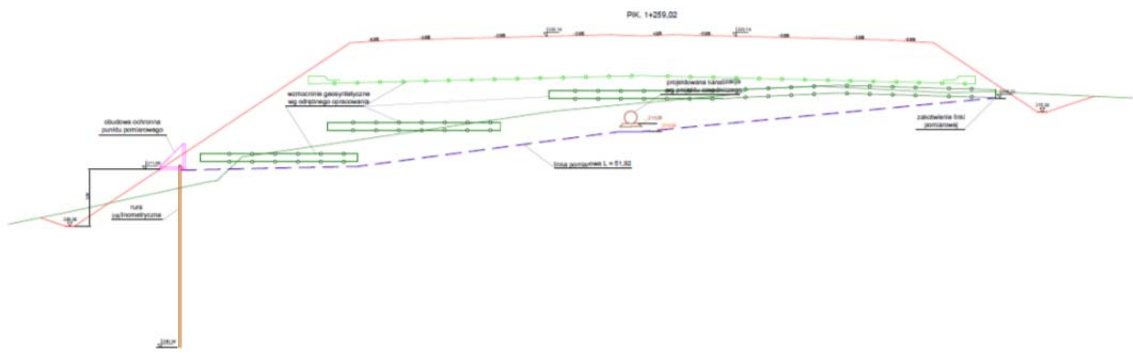

Fig. 3. The typical cross section with monitoring.

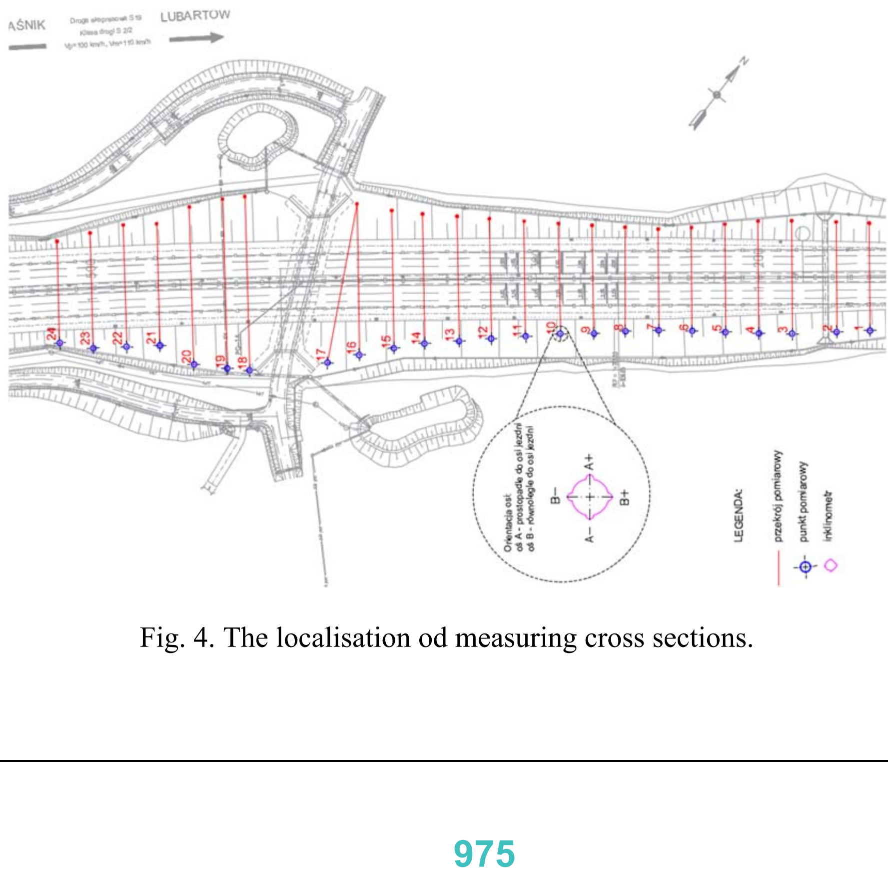

Fig. 4. The localisation od measuring cross sections.

Photo 1. An example of the measuring point - view of cabinet measurement in concrete enclosure

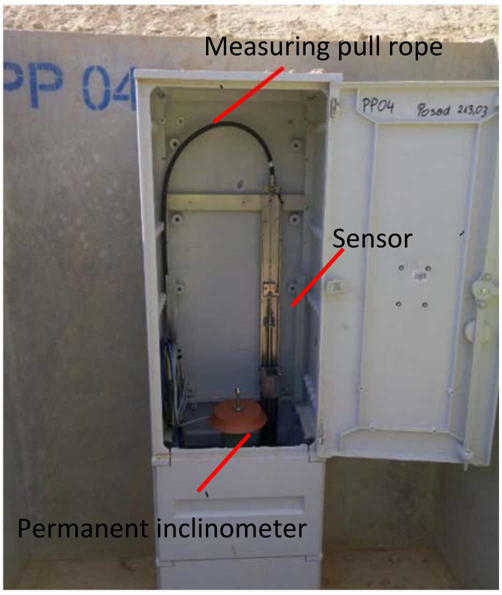

Photo 2. An example of the measuring point - arrangement of elements in the measuring cabinet

Inclinometer measurements

Inclinometer measurements are carried out automatically at 24 measuring points, where the inclinometer pipes chain with length 10m or 11m long were installed (depending on the cross-section).

In the pipes the IPI inclinometers chain were installed produced by NeoStrain company (Fig. 5).

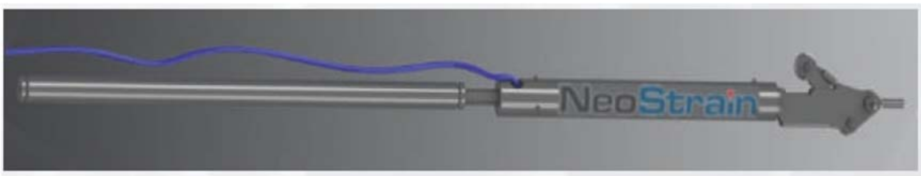

Fig. 5 The inklinometr IPI

These devices allow to create a chain inclinometer, which can be permanently installed in the standard inclinometer pipe. This solution allows to perform automatic continuous measurements of the horizontal displacement at various depths of the pipe. By using the IPI inclinometers system the angle change of the installed pipes and horizontal displacement of the soil can be recorded.

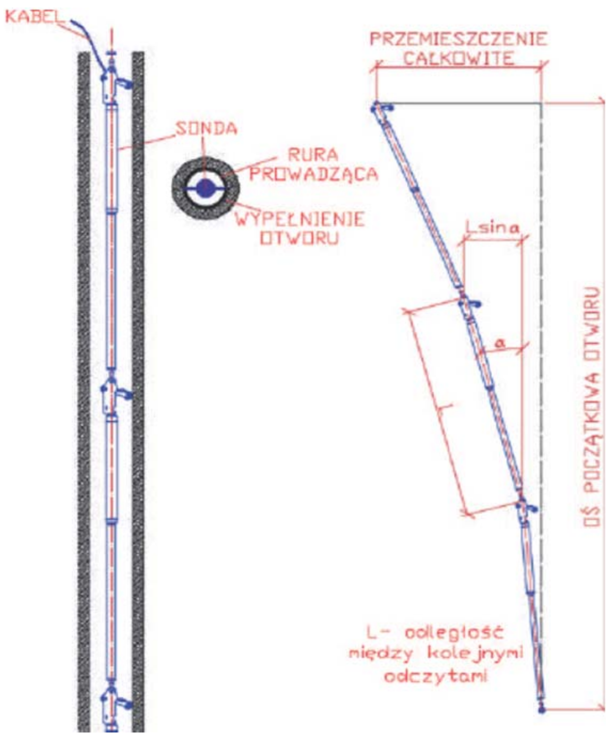

Fig. 6 The IPI inclinometers installation and basic measurement principle

Measurements using the measuring strings

Tension strings are installed under the monitored structure in 24 cross-sections perpendicular to the road axis. On the one hand the measuring string is anchored by special rigid anchor, and from the other connected to a displacement sensor Geokon 4450. The sensor measures the cord elongation of the string.

Mesasuring strings are made of corrosion-resistant steel with an additional protection of polyethylene coating. The materials provide the required operating time of the measuring elements.

The solution allowed the analysis of the current behaviour of the ground and the embankment during its work. The system which was used also allows to track the work of the structures with the ground along the warranty period, so the early detection and prevention of potential events can be detected. Used monitoring system will have a direct impact for costs mineralization of the potential diagnostics and repair, after all. As we well know cheaper is the prevention then future reparation.

Route „N-S", Ruda Slaska

Route N-S in Ruda Slaska (North - South) is the main route connection the A-4 motorway with all of Silesian agglomeration cities lying in the north direction. The route runs through former and present mining activities areas, and the geological fault "Saara" [Fig. 7]. Completed geophysical survey revealed anomalous zones showing discontinuities in the substrate. In order to avoid the effects of activation of fault zone and possible deformation of discontinuous a multi-layer structure made of geosynthetic reinforcement geogrids PVA Fok = 830 kN / m was designed.

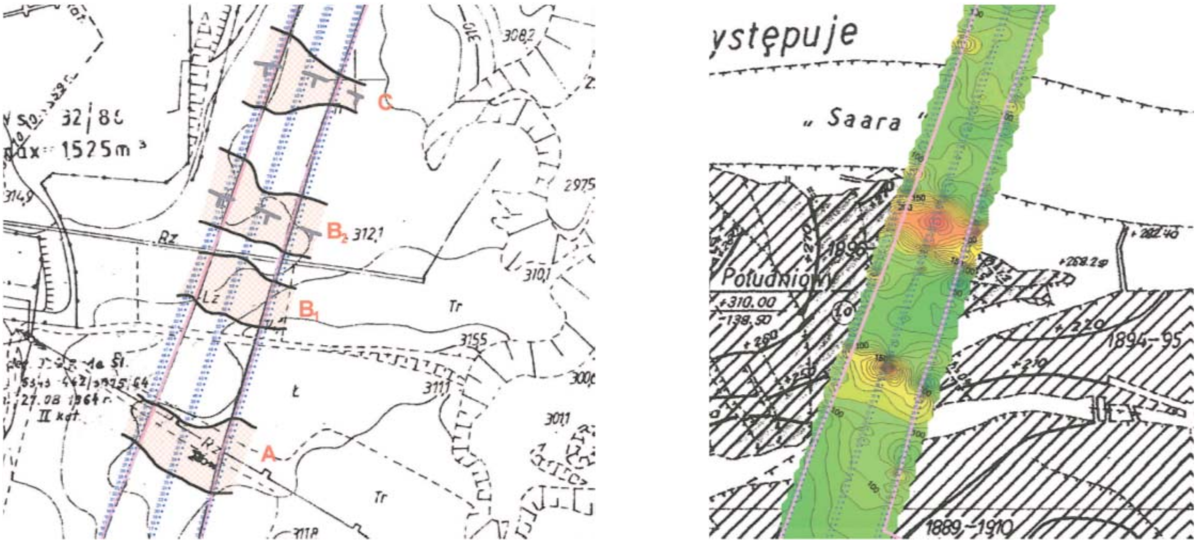

Fig. 7. The location of the discontinuities ground deformation in the area of fault „Saara" in Ruda Slaska [6]

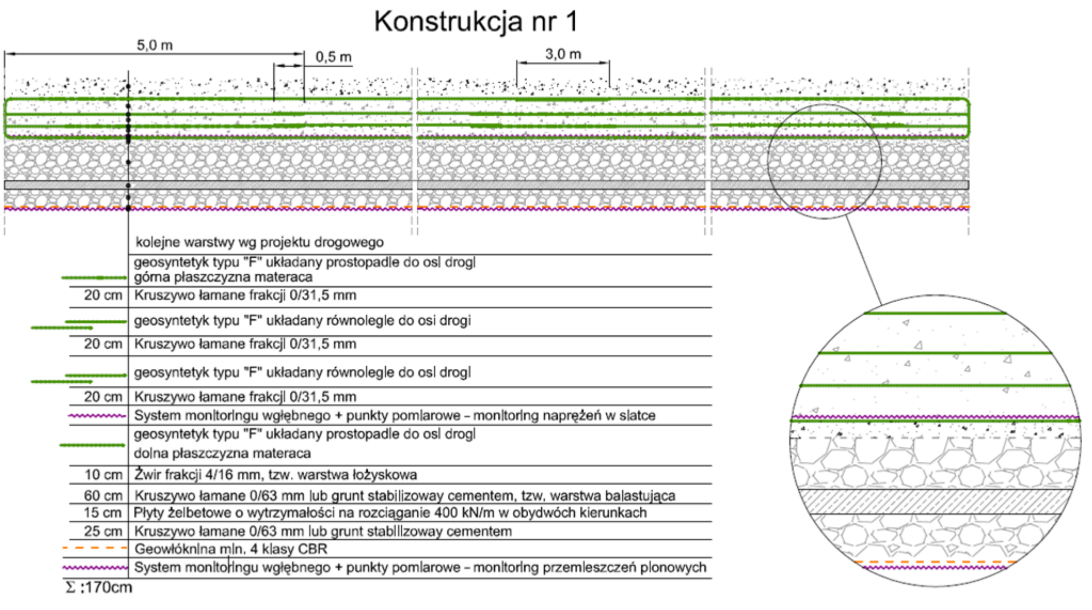

Fig.8 The cross-section through the monitoring structure

The monitoring System consists of two separate measuring systems [Fig.8]:

- the soil vertical displacement monitoring system
- and the geogrid elongation monitoring system.

The purpose of the first system is the monitoring of vertical displacements of the ground (detection of possible faults and / or discontinuous deformations). The purpose of the second system is to monitor the condition of geosynthetic reinforcement in the protective structure by measuring its elongation. The use of measurement systems allows to unambiguously locate the occurrence of deformation and determination of deformation reinforcement in place of deformation.

The data collected by the measurement system will be sent to the Database Server placed in the specified location by the Employer. On that Server the interface to check the current display and monitoring the status of potential alarms will be available.

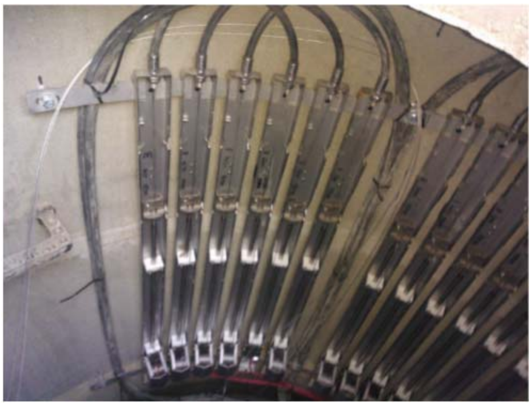

Photo 3. The view of the sensors which monitoring the vertical displacement of soil

Photo 4. The view of the sensors installed on geogrid

The events that can be detected by the measuring system:

1. Exceeding the set threshold for measuring vertical displacements;
2. Exceeding the set threshold for measuring the elongation of geogrid;
3. Exceeding the speed of growth of vertical displacements at a specified time (sudden increase in the value of displacement);
4. Exceeding the speed of growth deformations of geogrid at a specified time (a sudden increase strain).

Conclusions

The article discusses the major road objects, where the use of geotechnical phenomena were monitored. Some of them works more than four years and 24h / day and provides valuable information of the ground movements or the condition of the geosynthetic reinforcement. We should also mention that this type of systems are installed in a large scale in the large buildings construction like halls, stadiums, theaters, etc. by giving very valuable information about the condition of the structure, which translates into a direct relationship to the safety of users. However, each system should be carefully designed, to get really useful information. Ideally describe this situation Ralph B. Peck: "Every instrument installed on a project should be selected and placed to assist in answering a specific question. Following this simple rule is the key to successful field instrumentation. "[5]

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