Geodetic control in construction of steel roof structures

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Abstract. The article presents a complex of geodetic works conducted at construction of steel roof structures of the scientific and educational centre “Primorsky Aquarium” (Vladivostok, Russia). It is supposed that geodetic executive survey of constructed buildings is important. Monitoring and control are performed during every stage of construction process (excavation and foundation work, design of gridlines plan) as well as after finishing. Geodetic executive surveys are aimed to timely correction of conducted works for the quality construction of the subsequent elements. These surveys should be conducted regularly and they are often called current executive surveys. After conducting of construction works according to the definite technology and requirements to construction tolerance the final executive survey of the building and its general plan are made.

Introduction
Executive survey is carried out for conformity of detecting of a constructed object and its initial project plan. It allows determining the accuracy of issuing a draft of a building or structure. Also the survey provides us with the actual position valuation of a building according to its plan and to the height of the main elements and constructions. Current executive survey is held at the end of each stage, so the quality of work can be assessed by it. The current and final executive surveys are conducted by the same methods, as when performing location and survey works [1].

This study focuses on the complex of geodetic works conducted for geodetic control in construction of steel roof structures.

The research objectives are as follows:
1. To study the complex of geodetic works;
2. To determine the peculiarities of preparatory, field and data processing works;
3. To study actual methods of geodetic survey and its automatic tools.

Materials and Methods
Currently project drafts with data about factual parameters and deviations are used for executive surveys. According to revised SNiPs (Construction Standards and Regulations of the Russian Federation) different types of control are established. Also the following papers should be submitted before acceptance inspection: executive drafts, geodetic executive plans of constructions location [2,3,4].

In order to conduct executive surveys the following data for geodetic basis may be used:
– points of internal network or points of crossings of laying out axes – within the limits of separate buildings and constructions;
– signs of plan and height external network or signs of fixation of laying out axes – within the
limits of a building area.

In our research the executive survey was carried out on the construction of the scientific and educational centre “Primorsky Aquarium” (Figure 1), situated in Vladivostok, Russky Island. The island is the largest one in Primorsky Territory. It is located in the Peter the Great Gulf in the Sea of Japan.

Figure 1. Main building of the aquarium with dolphinarium

The principal object of the constructed complex “Primorsky Aquarium” is its main building with the dolphinarium. The construction is made in the form of a lying sea shell. The main building includes two constructions with different number of storeys. Bearing constructions of the aquarium roof makes tridimensional system which consists of roof trusses in different directions. The principal trusses are set according to radial axes and joined with the pillars by the capitals. The complex outline of the roof with roof timber trusses is made due to sub-trusses placed along the axes. A location survey on laying out the axes of the capitals is conducted by electronic tacheometer Trimble 3600 from the points of plan and height grounding (Figure 2). We use the local systems of axes (Vladivostok) and the Baltic Sea Level Datum of 1977.

Figure 2. Scheme of the points of plan and height grounding

The orientation of the electronic tacheometer is carried out according to the “backsight” program with the use of tripods, which have the reflectors on them, centered over the points for a stable position of reference points. Targeting within the laying out of points is made on a prism or reflective sheeting. After the process of orientation we use the projection of points to fix the axes. The basis line is the axis between the same points of intersections of the capitals and the trusses in the draft. Taken-out axes on the built-in parts are marked according to the marks with paints or markers. Before the installation the capitals should be designated with the axes according to their abutments. Next stage
includes setting the marks of axes on the built-in parts of the capitals and their adjusting to the already marked points. The vertical control of the capitals arrangement is conducted by side leveling and with the use of the plumb line. It is necessary to make an executive survey for assessment of work accuracy after the capitals installation according to the draft and their welding to the embedded detail. Finally, the data are processed by the “AutoCAD” software to design the executive plan. This plan allows determining the quality of location survey and the accuracy of axes fixation on the reconstruction area [5].

As such geodetic control is of utmost importance in conducting of engineering and geodetic works. Setting the trusses and the arches of steel roof structures, precise installation of roof elements should be done under the geodetic control and according to the approved drafts. To meet the requirements it is necessary to conduct the executive survey of the accuracy of geometric parameters of roof elements apart from the geodetic survey, which includes factual height and vertical control of constructions. There should be random checks on the control of accuracy [6].

A special focus should be put on the control of the accuracy of the elements, joints and constructions, which position influence upon bearing and fencing characteristics of the roof as well as on the accuracy of construction during the following stages of work. The geodetic control of constructions positioning according to the draft is conducted by the coordination of the control points – the markers.

The control points are the markers from self-adhesive reflective sheeting (reflector) which have the size of 15x15 mm or 30x30 mm. The centre is marked by the cross. The markers on the heel joints of the trusses (which are the control points as well) are set between the upper and bottom chords. They are placed on the side oriented towards the centre of symmetry for the sake of construction works. The following figure (Figure 3) shows the position of the control points on the heel joint of the trusses.

![Figure 3. Position of the control points – the markers](image)

On the arch constructions of the braced framing elements the control points (the markers) are placed in the apertures and in the centre of the highest point (the ridge of the roof). They are marked by the paints for the subsequent work with the use of range polarized. Instead there can be a plank with the marker welded to the arch. The control points on the ridges of the arches are placed on the facet which faces the definite radius on the upper edge (Figure 4).

![Figure 4. Position of control points on arches](image)
After conducting instrumental control of the construction geometry and preparation of the executive plan all control points should be fixed on the construction elements following the site assembly on the building way.

Traditionally the control of plan and height position of trusses and arches is conducted with the use of electronic tacheometre. The axis of the truss is supposed to be the basic line. The coordinates of the control points of the markers are projected on the basic line. As the result there are deviations from the project axes in the plan and in the image [7]. It should be mentioned that we use electronic tacheometre in geodetic control of the braced framing elements – twofold arches. Single arches, situated between the braced framing elements, are constructed on the trusses, and their position is specified by the accuracy of the capitals and trusses construction. The position of in-between arches is controlled by the measuring tape.

Deviations from factual position of constructions should not exceed the limits shown in Tab.1

| Table 1. Limit deviations from factual position of constructions |
|---------------------------------------------------------------|
| **Parametres** | **Limit deviations, [mm]** | **Control (method, quantity and type of recording)** |
| 1. Points of heel joints | 10 | Instrumental, every joint, a log book |
| 2. Displacement of trusses and beams of crossbars from the axes on the pillar heads of the framework flat area | 15 | Instrumental, every element, geodetic executive scheme |
| 3. Pitch of deflection (curvature) between the points of fixation of joint parts of chords and a beam of a crossbar | 0,0013 from the length of the constructed part but no more than 15 | Instrumental, every element, a log book |
| 4. Distance between the axes of trusses, beams and crossbars on the upper chords between the points of fixation | 15 | Instrumental, every element, a log book |

Current geodetic control and the order of construction process are conducted according to the technological plans of the steel roof construction of the scientific and educational centre “Primorsky Aquarium”. The executive survey of planned and high-altitude positions of the lower and top chord is carried out after final assembly and construction of every truss in compliance with the project plan.

The marks are placed on buildings and constructions for determining the accuracy of foundation settlement. In coordination with the design organization the marks placement is outlined. The location of marks should provide favorable conditions for performance of leveling works. Therefore they are placed at the corners of a building or a construction, at a settlement joint on both sides, and in the places of abutting of cross cut and lineal walls. The distance between the marks depends on the engineering and geological conditions, the settlement construction, the expected degree of the settlement and its inequality, as well as on the aim of the measurement [8]. It is recommended to mark not less than three points on each section for hydrotechnical constructions divided into sections. If the width of the section is more than 15 metres, there should be more than four marks. Also several lines of marks (on the ridge of the construction and in the lower layer) should be put around the perimeters of upper and low pools. For bulkhead walls the marks are pointed within the distance of 15-20 m around the perimeter. On the foundation plans, plotted to a scale of 1:100-1:500, the places of these marks are usually indicated by symbols which have indexing number.
Bearing roof constructions of the dolphinarium is a tridimensional system consisting of basic and arch trusses. To make this system rigid braced framing elements, beam knees and tie bars between the arches were used. The territory of this complex comprises about 35 thousand m² and consists of the aquarium building, scientific laboratories, parking lots, and the park for walks. The total volume of water in the water areas of the centre is 25 thousand tones.

Geodetic surveys of deformations, horizontal and vertical shifts are aimed to get information for monitoring. Geodetic monitoring is a set of measures and engineering surveys which is used to diagnosis, predict and prevent geometrical deformation of buildings and constructions throughout the whole period of building and construction works and during their operation.

Classical geodetic methods of deformation measurement are as follows:

- Geometric leveling with the use of horizontal beam of aligning. It is used in monitoring of vertical deformations of significant quantity of available points of buildings and engineering constructions.
- Trigonometric leveling with the use of a leaned beam of the geodetic tool and geometric formulas. This method is used for determining of vertical deformations in hardly accessible points and the points, situated on different levels.
- Hydrostatic leveling, which is based on the liquid properties in two communicating vessels. Typically this method is used for highly precise monitoring of vertical deformations in hardly accessible points and the points, situated on the same level.
- Microleveling with the use of geodetic microlevels is not an independent method. It complements to highly precise geometric or hydrostatic leveling. Microleveling is considered to elicit precision guided vertical deformations within nearby points (less than 1.5 m).
- Coordinate instrumental methods are geodetic methods of marking and polar coordinates which allow determining plan or special positioning of points on the object. They are aimed to coordinate centres of deformation marks cyclically. Also they are used in determining of horizontal deformations.
- The next group of methods includes measurement of deviation of points from the points within one vertical flat area.
- Photogrammetric methods contain recurrent shooting of the construction parts and processing of photos. These photographic materials allow comparing coordinate points which are available due to the stereo effect of the previous cycles of shooting. These methods require special tools: a photogrammetric camera or a digital camera.

Currently land surveyors use the following modern methods:
- Laser scanning. This method is based on the principle of measurement of distance without any example with the help of a laser by impulse, phase, and impulse and phase methods. The measurement is conducted through the mirror, quickly swiveling round the vertical axes. The mirror allows making a lot of measurements of distances to the object. The laser swivels itself in the horizontal axes. As such there is a scan of a building or a construction consisting of a great amount of points (more than several millions) which result in the image.
- GNSS methods are based on the usage of satellite tools. Due to the satellite systems land surveyors get the coordinates of the receiver tool by calculating pseudo range with ephemerid and time-dependent information. This method is supposed to be difficult to use because deformation marks are often unavailable for satellite signal. Kinematic methods are also unable to meet the requirements of accuracy. On the other hand highly precise and irreplaceable data can be obtained in case of static measurements, made by relative method and forced centering. The conditions for technical operation of hydraulic engineering constructions define the choice of a class of measurement for definition of the deposit and the corresponding method of work. Before the start of measurement work it is necessary to put benchmarks of the network. They are as follows:
  - deep – a fundamental geodetic benchmark, placed in the almost incompressible soil layers,
  - ground – a benchmark, placed below the frost depth,
• wall (or a wall mark) – a geodetic benchmark, placed in the wall of the construction which has almost finished its settlement

After the settlement of a benchmark it receives the marks from the nearest points of the state geodetic network. Sometimes the calculation is made according to the universal system of elevations. The marks for surveys, put in the construction, form a supervisory network. Their placement has to provide favorable conditions for performance of geodetic works [9].

Horizontal shifts are determined by the following methods:
• survey of the points within one vertical flat area, which is used in the case of immobility of extremes of lines – survey points.
• Measurements of small (parallactical) angles which allow measuring the angles between continual orientation of the vertical flat area and orientation on every transitional survey mark within this area.
• Certain techniques are used without preliminary calculation of survey marks coordinates within different survey cycles.
• Triangulation is used for observation of horizontal deviations of hydrotechnical constructions in which survey points are not connected with the network points by linear measurements.
• Traverse is based on measuring of sides and angles of closed polygons which are made by benchmarks of the network and survey points on the construction.
• Trilateration is used in a triangle construction element formed by a survey point and two networks.
• The combined method is also used in the measurement of horizontal deviations in case of variability of survey points. Usually the survey of the points within one vertical flat area is combined with triangulation, traverse, trilateration.

The measurement of horizontal shifts of constructions, as well as the measurement of their settlement, can be also carried out in the photogrammetric way.

Summary
Geodetic control and monitoring are of utmost importance in conducting of engineering and geodetic works. In the research we studied technological stages of geodetic works for the roof construction control; a set of measures and engineering survey aimed at diagnosis, prediction and prevention of geometric deformation of constructions; actual tools and methods.

The complex of geodetic works within the scientific and educational centre “Primorsky Aquarium”, conducted for geodetic control of steel roof constructions, was made in compliance with regulatory documents and standards.

It is proposed to use current monitoring of all construction elements for control of their condition and operation. It will provide safe functioning of hydrotechnical constructions according to the regulations and requirements of technical maintenance.

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