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Measurements of Roofs For Diagnostic Purposes

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Summary. This paper depicts selected methods used in measuring roofs for diagnostic purposes, as well as conclusions from experimental research about their use to date.
Key words: measurements, suspended roof, diagnostic purposes.

DIAGNOSTICS OF STRUCTURES AND MEASUREMENTS FOR THEIR PURPOSES

The diagnostics of a building performed by constructors is generally understood as a determination of its technical condition. It also covers a survey and prognosis of the way a construction will behave in differing conditions [1]. Often, besides basic surveys of strength, durability, and the technical condition of constructional elements of a building, what is necessary is a record of its geometrical structure (in various scopes). The diagnostics of a building includes the determination of its technical state, usually when it shows symptoms of unfavourable change in the geometry, or improper work [10], and also in pre-emergency situations in order to identify the cause of such a situation and undertake appropriate preventative action [8, 12, 13].

The measurements of a building for diagnostic and prevention purposes can be generally identified with all kinds of monitoring measurements, and measurements related to marking displacements and distortions as understood in technical standards. This excludes set out and inventory measurements used to update the geodetic and cartographic database. The common denominator of all these measurements is the goal for which they will be used – and which is gaining all data about the geometry of a building that is necessary to determine its technical condition [1].

MEASUREMENTS OF SUSPENDED ROOFS

Standard measuring techniques (the polar coordinate method, spatial sections, laser scanning and digital photogrammetry) allow to determine changes in the placement of the constructional elements of a roof with the precision required in a comparative analysis, which includes the observed and predicted displacements of the nodes of a roof [1]. Constructors of suspended roofs determine the expected precision of the placement of a particular detail in an accepted local coordinate system within a range of 1 cm to 5 cm. Seemingly, this appears to be relatively simple to attain with the use of modern reflectorless total stations, laser scanners or the use of photogrammetric methods.

The aforementioned methods of measurement concern a periodic registration of the geometrical structure of a large-span roof, the interpretation of which, taking into account the design and structural conditions, as well as outside factors [6, 7], will allow an objective evaluation of the geometrical state and its changes in relation to occurring forces. This can constitute the basis for findings of a safely functioning roof, or a possible danger of a breakdown. The changes in geometrical features of a construction can be associated with the current state of forces occurring in the construction and their changes caused by various factors, which can be simultaneously recorded [1].

MEASUREMENT METHODS USED AND CONCLUSIONS DRAWN FROM THE CONDUCTED RESEARCH

The coordinates of points in a building are established in a three-dimensional space based on the results of angular-linear (combined), and height measurements. This paper portrays selected, previously mentioned methods of measurement and conclusions from the research [1] conducted for the construction of the suspended roof of the open-air theatre in Koszalin [9] (Fig. 1).

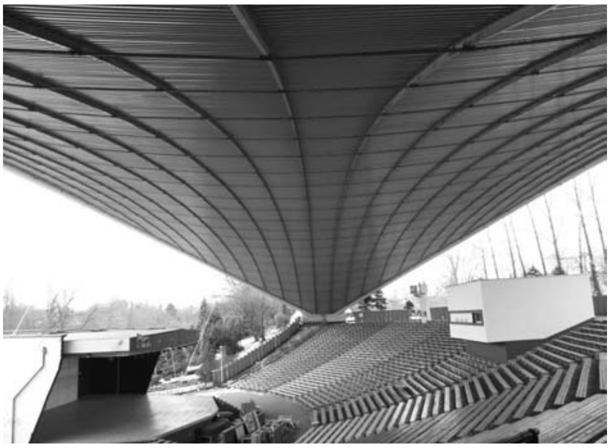

Fig. 1. Suspended roof of the open-air theatre in Koszalin

SPATIAL INTERSECTION METHOD

When the spatial intersection method is used, measurements of vertical and horizontal angles, to previously signalled points on the construction are taken from a minimum of two stations. These points are either painted or targets and signs are attached, or temporarily marked with a laser beam.

The results of conducted empirical studies [1] clearly show that the spatial angular intersection method is ineffective when it comes to observing a greater number of cylindrical details of a construction from only one post. An observation of some dozen details would require choosing many measuring bases. Furthermore, it is obvious that a construction detail that cannot be determined clearly is not the proper target for the angular observation due to the fact that its image changes in the field of the telescope view. In this situation it is necessary to introduce reductions (each calculated as elements of the targets eccentricity), which, due to the significant effort required, is not justified in the case of diagnostic measurements.

In the case of signalling only selected controlled points of a construction, the angular intersection method can be applied in diagnostic measurements. However, the amount of time that such a measurement will take, the effort required and the amount of equipment required make this method less effective in comparison with the axial method. The effort required in this method and the amount of time the measurement takes also speaks against the spatial intersection method when it comes to tension structures. In the case of tension constructions (which are less susceptible to changes in outside factors such as temperature, insolation, and wind) this method's effectiveness rises due to a smaller significance of the limitations pertaining to time and conditions of observation, as well as a greater precision. Nonetheless, its application should only be seen when there is a need for recording the location of specific spots, and not the whole constructional grid of the roof.

METHOD OF POLAR COORDINATES AND FREE STATIONS

The polar coordinates method can be seen as a very effective method, especially due to the possibilities which have been created by reflectorless rangefinders and infrared rangefinders which measure the distance to points that are signalled with a reflective tape. It is also effective when used for execution related measurements, displacement measurements, as well as others in the field of engineering geodesy. Using a free stationing is currently associated only with a skillful use of the technical possibilities of modern equipment. The basic advantage is full freedom in the choice of posts that are adequate for the terrain and carrying out the assignment, as well as the lack of need for centre the instrument over a sign. It is a versatile technology that combines the intersection method with the polar coordinates method.

Based on the results of test measurements [1, 6] it can be stated that with the use of some reflectorless total stations it is possible to have a precision of 3 cm to 5 cm when determining the location of particular details in the construction of a roof.

Because of the rangefinder's and the construction detail's properties, control points can be assumed to be points on the surface of the detail (Fig. 2). There will be no need to make corrections to the result of the distance measurement in order to recalculate for the distance to the middle of the detail. The consequence of such an action will be a registration of a spot that is no more than 20 mm away from the defined point on the surface of the constructional detail. Defining the occurring eccentrics or geometrical interpretation of a beam falling onto the surface of the detail can be deemed pointless. Not applying the appropriate reductions to the results of the distance and direction measurement due to the properties of the cylindrical constructional detail, as well as the properties of the equipment and the method, can result in the registration of a point that is located no farther than 27 mm from the centre of the cylindrical detail.

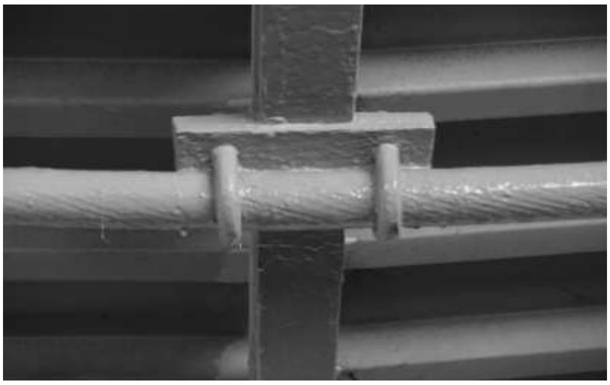

Fig. 2. Cylindrical detail – construction node

The above conclusions find their confirmation in the results of the research conducted on the test building in the scope of measurements to cylindrical details in the constructional nodes of the roof [1]. In the case of other details, it is necessary to verify these measurements, for example with the use of a constructed instrument [1, 2, 13] and with an adequate modification of the testing procedure. Such an approach can be applied only with interventional monitoring and only when using a set of instruments which has been verified based on experiments which were previously conducted in an appropriate setting: an instrument – a signal, meaning a reflectorless total station – a detail. In this situation, mainly the congruence of the line of sight and the axis (centre) of the laser beam should be evaluated, as well as the size of the beam through a determination of the influence of these elements on the result the measurement of the distance to the detail.

In observation of plane constructional details, test results [1] show that the possibilities of the polar coordinates method with the use of reflectorless (laser) rangefinders are quite vast, especially when it comes to the precision of distance measurement (even below 1 cm).

It should be noted that the differences in coordinates and mentioned errors in coordinates also reflect the influence of errors related to the setup of the signals and instruments over the reference points and the sign marking the station of the instrument (centring errors) The target lengths to observed spots of the roof, as well as to reference points, can vary from a few meters to 100 m.

Keeping this in mind in our own research, reference points (as signals and not posts) were located on fixed elements (buildings) in the immediate vicinity of the structure (unrelated to the construction of the roof). Points marked with signs, fulfilling the function of measurement stations are treated as accessory in the construction of a grid that allows the measurement and calculation of the coordinates of the reference points. The instrument stations can be treated as free stations during periodic observations and centre of total stations above them can be done while controlling for possible gross error occurrence. Similarly, calculating the height of the target axis based on a known height of the post and the height of the instrument must be treated only as an element of control.

Limitations resulting from the properties of the equipment (including the influence of differences between the target axis and the axis of the rangefinder), as well as the properties of the target (the detail) and their effect on the veracity of the measurement when using different types of reflectorless total stations, will be the subject of a detailed research. There is a lack of data on this type of research, including the means and procedures of judgment of a total stations use for a particular measurement assignment, determined also by the properties of a target (detail).

When using constructed targets [1, 3] clearly signaling the points which are observed and which allow the measurement of a distance with an infrared rangefinder to a reflective tape (Fig. 3), it is possible to achieve a precision below 1cm when defining the location of a particular signal.

Fig. 3. Constructed target attached to the construction of suspended roof as controlled point (left side) and on the abutment as control (right side)

In some situations the ideal solution is using a total station equipped with a laser rangefinder (if the signal is observed at an inconvenient angle) and a zenith eyepiece. An ideal solution in some situations is the use of a total station equipped with a laser rangefinder (if the signal is observed at an inconvenient angle) and a zenithal eyepiece. The use of motorized total stations with an automatic target recognition system, due to a limited precision of "finding" the center of a target with a reflective tape, can only be used to speed up the measurement, for example by using it to generally target the signal.

Research results [1] justify stating that with a previously verified instrument, one can conduct measurements with the axial method twice only in one position of the telescope (due to its equipment with a zenithal eyepiece) treating the measurements as if made from two independent free posts (change of a post for example through a change in the height of the stand, which greatly shortens observation time while simultaneously giving a necessary control element in the form of a second appointment of coordinates of the post, followed by observed points).

The polar coordinates method with the use of 5" – 7" total stations and free stations allows to attain a precision of up to 1 cm for position determination for the control (signal) points of a construction, when maintaining appropriate observational conditions (stable temperature, cloudiness, insolation and windiness). The results of the conducted research [1, 6] confirm that steel constructions of suspended roofs, especially open ones, are dynamic buildings, clearly susceptible to temperature changes and air movement. Due to the above, it is not practically possible to obtain a precision higher than to the nearest centimeter.

The polar coordinates method can be considered the most effective in the case of registering from over a dozen to a few tens of particular points in each measurement period. It is not, however, effective in inventory measurements, mainly due to its constructional properties and dynamics.

PHOTOGRAMMETRIC METHOD

Contemporary tendencies of close range photogrammetry in the scope of engineering and industrial applications focus on using digital photogrammetric stations and digital images, including non metrical ones, obtained with amateur digital cameras. Photogrammetry methods constitute an important supplement of other methods and in many cases prove to be rather irreplaceable. Often, the possibilities of their use in monitoring geometric features of a building are pointed out, along with a precise engineering inventory in the use of pictures captured with cameras with a matrix above 8 million pixels.

The experiment conducted during the research [1, 5] (Fig. 4) justifies the conclusion that the photogrammetric method using amateur medium resolution digital cameras in registering the geometrical structure of roofs for diagnostic purposes is useful especially when the registration regards the state zero and comprises all of the roof construction.

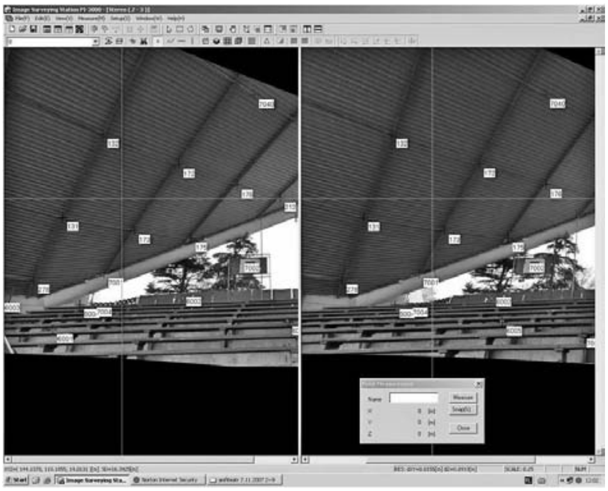

Fig. 4. Measurements of coordinates using Topcon Image Surveying Station PI-3000

This conclusion refers to tension structures for which the expected accuracy of determining the location of the node of the construction grid is between 3 cm and 5 cm.

Using the photogrammetric method requires, generally, determining the coordinates of reference points in an external frame of reference, and what goes with that, determining, before or during the registration, more points of known coordinates, where targets constructed by the author can be attached [1, 3].

LASER SCANNING AND TERRESTRIAL LASER SCANNERS

Laser scanning is, in geodesy, one of the biggest technological achievements of recent years, which is perceived not only as a new approach to spatial inventory, but also more and more often to monitoring the object's shape. The scan itself – the effect of scanner's work – is only intermediate, that is an effect of a measurement used for creating a spatial model and/or allowing a measurement in a cloud of spots. The effect of scanning is a point model covering the area of an examined object.

It has to be clearly emphasized that using the laser scanning technique allows to model and measure of qualities of geometrical elements of a construction by assumption without the need to signalize their controlled points, which is difficult or even impossible in certain situations.

Conclusions from the experiment concerning the use of laser scanning technique with regards to the examined roof [1, 4, 6] apply first and foremost to the scanning resolution. For the precise modelling the connections between the elements of the examined construction, in case of steel arches and their connections with ropes, a resolution in the range of 5 mm is sufficient. However, appropriate modeling nodes of the grid – details, which constitute connections of ropes and I-sections (the largest quantity), requires scanning with the resolution of at least 2 mm (Fig. 5) made from a number of stations, and then joint compilation after merging a few clouds of points. The blind spots of the field are therefore limited, and spots on a greater area of given element or detail are registered.

Due to the dynamics of change of the geometry of the construction of the roof (especially in its middle part), which is the result of changes in temperature, a registration of the geometrical structure for diagnostic purposes should be conducted at a stable temperature, zero insolation, and a lack of strong wind. Due to these factors, measurement time should be the shortest possible, and the scanner that is used should be the fastest possible. For a full description of the geometry of the construction of a roof, a few scanners can be used simultaneously, and scanning can be done from four stations (the ideal solution would be a simultaneous use of four scanners) placed symmetrically under the construction of the roof. Each fragment of the construction should then be scanned from at least two stations, with a resolution of at least 2 mm x 2 mm (if possible, at the same time by two scanners, scanning the same fragment of the construction of the roof from two different stations).

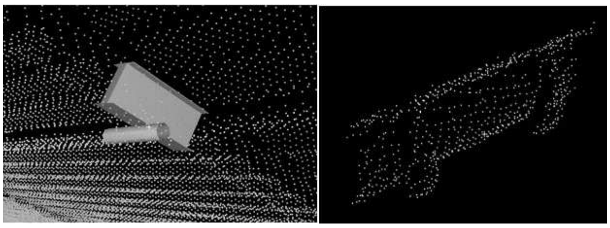

Fig. 5. Modelled node – connection of rope and I-section (left side), detailed part of node in cloud of points with resolution of 2 mm (right side)

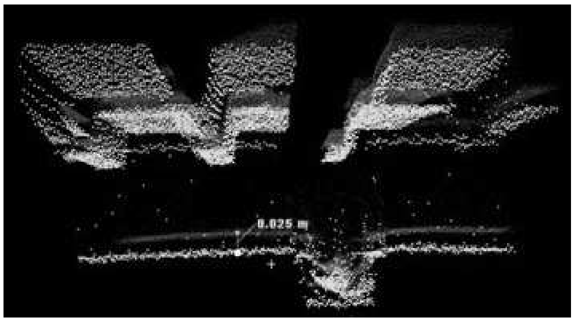

Fig. 6. Two clouds of points registered after a couple of hours (movement about 0,025 m of elements of the roof in the middle part of it caused by a temperature change)

An important limitation in the use of a laser scanner in the case of open roofs is its minimal temperature working range, which begins at 0 ºC. In practice, this excludes the possibility of a registration during winter, when the roof is burdened with snow and ice. Another limitation is a lower scanning speed when scanning in a so called upper window, meaning in a range above 32.5 º from the instrument's horizon and a limitation on the choice of the scope of the measurement in the form of fragments of a rhomboid plane stretched across the sphere. In an instance where posts are located below the scanned object, a lack of freedom in the choice of the scope of scanning, as well as a limited scanning speed both play an important role.

Taking the above statements iinto consideration t can be assumed that the use of a terrestrial laser scanner for a registration of the geometrical structure of selected fragments of the construction of a suspended roof is greatly limited and can, in practice, only refer to a few points, elements or details. In the case of typical roof structures, and roofs with a smaller dynamic and less susceptibility to the movements caused by wind and temperature changes (Fig. 6), laser scanning is undoubtedly the most effective method in spite of the fact that it registers a great amount of excessive observations which include points outside the support construction on the coat of a particular roof [1].

CONCLUSIONS

There is still a need for an evaluation of the usefulness and effectiveness of applying various measurement methods [11], at the same time checking the possibilities of application of various geodesic techniques when it comes to a registration of the geometrical structure of various building constructions, including roofs. The result would be a designation of appropriate methods and tools of measurement, as well as determining the conditions of their use in order to obtain information that is diagnostically necessary. This aims at the development of a methodology in registering a geometrical structure of exemplary buildings for diagnostic needs [1].

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POMIARY PRZEKRYĆ NA POTRZEBY DIAGNOSTYCZNE

Streszczenie. Artykuł przedstawia wybrane metody stosowane w pomiarach przekryć na potrzeby diagnostyczne oraz wnioski z dotychczasowych badań doświadczalnych odnośnie ich wykorzystania.
Słowa kluczowe: pomiary, przekrycie wiszące, diagnostyka.