Creation of a Surveying Base for an Ice Rink Reconstruction Project

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The contribution deals with surveying works needed for rebuilding project of O. Nepela ice rink in Bratislava. An essential part is review of the existing documentation with actual parameters of the selected elements of ice rink construction, which will serve as a base for the reconstruction project. The most important part of surveying measurement is to establish a control network, from which follows measurement of the detailed points of selected elements. Next section of paper deals with a choice of a suitable type of control network and its optimization in terms of availability and required accuracy. Finally, the contribution deals with the measurement of the spatial elements and with a 3D model creation of the main supporting pillars, entries, stands, stairs and ice hockey ground.

Key words: *Ice rink, reconstruction, local control network, network optimization, measurement of the pillars, 3D representation.*

Introduction

The ice rink of Ondrej Nepela in Bratislava was a subject of several reconstructions in the past, last time from 1989 – 1992 on the occasion of the World Ice Hockey Championship in former Czechoslovakia (Kimijan, 2008). Nevertheless, the stadium did not meet strict safety, sanitary, technical nor aesthetic criteria for organizing the top international sporting events, such as is rapidly approaching the World Ice Hockey Championships 2011, which will be held in Slovakia.

The Ice Rink of Ondrej Nepela in Bratislava – historical context

The first ice rink in Bratislava with artificial ice began to build up just before the Second World War, on the 28th of October 1939 at the current Trnavská road. The ice rink was officially put into operation shortly before Christmas in 1940 and the first official hockey match was played on the 21st of December in 1940. However, the rink was not covered at that time, the sector for fans around the barriers took about 300 fans (Kimijan, 2008).

The first stands for fans around the playing area were built in the years 1948 – 1949 and immediately increased the capacity up to 11 000 fans for standing. The stadium was roofed in 1950 on the occasion of the European Championships in the figure skating.

The last larger reconstruction of the stadium was performed in the years 1989 – 1992 on the occasion of organizing the Ice Hockey World Championship in 1992 in Prague and Bratislava. Its interior, including the auditorium, player's cabs, all technical spaces and new steel roof were completely rebuilt. The auditorium had a capacity 7747 places to sit. However, the inglorious pillars that obstruct from the several locations the view to the playing area remained unchanged (Kimijan, 2008).

Also in the recent years, several reconstructions have been performed. New sky boxes, Sky Europe Lounge, renovated press room, player's cabs, as well as technological equipment, including modern information video cube above the ice hockey ground were installed.

Reconstruction project

The project of fundamental reconstruction was prepared in accordance with the financial investor capabilities and obviously with the possibilities of the location. An important part of the project was an effort to meet the requirements of the International Ice Hockey Federation (IIHF) presented by the Slovak Ice Hockey Federation (SIHF), which was not always easy on a reconstructed building and naturally had its limits (Kimijan, 2008). To the most important intervention will belong new overlay of the stadium with a steel structure with a generous span of 76 m, carried by the new pillars in module 10 m. This solution will enable destroying the pillars in the auditorium, which composed a negative feature of the old ice rink – the pillars from the tenth series obstruct the view of fans.

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A significant intervention into the concept of surroundings will be a glazed facade, which will arise by extending the groundplan about the fans break areas and will hit to the current sidewalks and surroundings (Fig. 1). A modern expression of the facade should meet current requirements and should partially neutralize the great mass of the stadium. The castellated reflective and transparent glass used on the facade is a mean for expressing the content of the object – cold and hot passion. Distorted reflection of the surroundings on the all-glass facade will change during the event to live interpretation viewable from the exterior by highlighting the social space.

Fig. 1. Visualization of the projected ice rink of O. Nepela (http://www.asb.sk).

From the significant changes inside stadium it is necessary to mention lifting the ice hockey ground about 1,4 m, which will improve the curve of visibility and the seats will be placed up to the glass separating the ice hockey ground. The break areas will be extended, communication centres and escape routes will be improved and new boarding places will be built. A training hall will be also reconstructed and will have two ice hockey grounds with underground parking. The planned reconstruction should be completed at the beginning of 2011 (http://www.asb.sk/).

Surveying measurement for the purpose of verifying the existing documentation

In order to prepare a quality project documentation it is always necessary to know the actual state of an existing structure and have its documentation that is essential for designing new structures and technologies that interlock to the actual state. However, such a documentation not always exists or does not contain all the necessary formalities, which are important for the preparation of a new reconstruction project.

In the case of reconstructing the ice rink of O. Nepela in Bratislava was available project documentation in the form of 2D views and longitudinal and transversal profiles. Due to the reconstruction of the bearing steel construction, extension of the stands, lifting the ice hockey ground and other reconstructions, which will follow on the existing state, it is important to confront the existing documentation with the actual parameters obtained by direct measurement. Therefore, after the careful consideration, the following requirements for surveying measurement were introduced:

1. measurement of the existing pillars of the steel roof structure of the stadium in the outer bottom and inner top part,
2. measurement of the existing supporting pillars in the corners, next to the stairs of the stadium,
3. measurement of the ice hockey ground, stands, stairs, entry and exit areas of the stadium,
4. measurement of the control heights of the particular floors inside the stadium.

Control network

With respect to the submitted requirements for the surveying measurements, a network of reference points was established (fig. 2). Since a part of the supporting pillars is visible at the outer bottom part of the stadium and the other part in the inner upper part below the roof, a control network for outer and inner measurement was needed. Subsequently, a network with 5 reference points for outer and inner measurement was proposed and established. Given the limited transition from the outer part to the interior only through one entry, it was necessary to perform an optimum design for measuring the control network in order to achieve the required positional accuracy. The heights of the reference points were determined by means of a precise levelling method using the Trimble DiNi12 digital levelling instrument, which guarantees the required accuracy of height determination. Therefore, the height measurement is not further discussed.

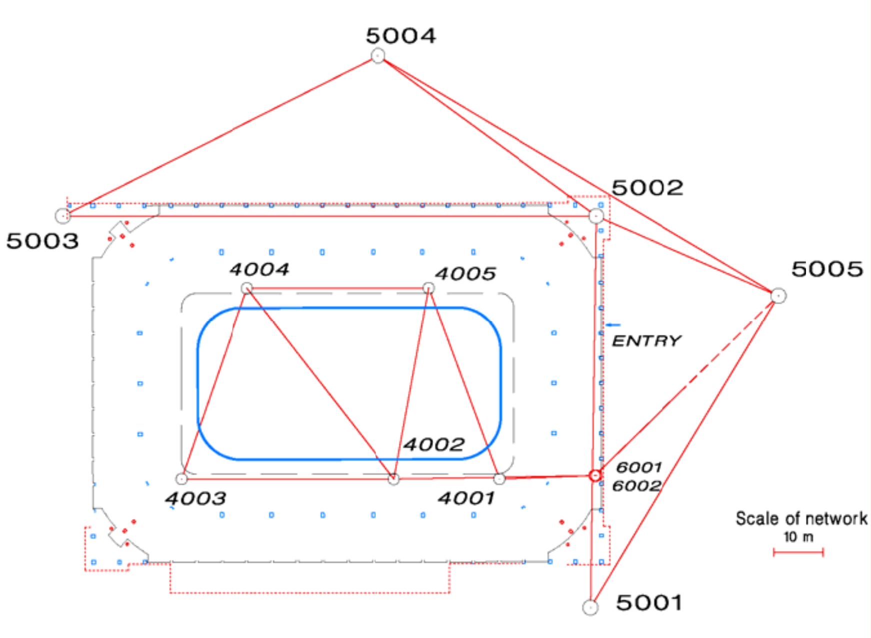

Fig. 2. Control network.

A priori analysis of the control network

A priori analysis of a network is the analysis of the quality and functionality in creating the network project, i.e. prior to its physical establishment. At given configuration of points of network and given structure, in which the measurement technique and instruments are considered, the processing of measurement results yield in estimation of the coordinates (network parameters) and its accuracy characteristics. Before performing measurements it is possible consider whether the proposed network will satisfy the demands that will be imposed on it.

It has to be decided whether the network will be built as a single-stage or multi-stages, and if it will be single or multipurpose. It has to be decided about the instrumentation, including their accuracy characteristics. Consideration about the optimal structure of a network must be based on the purpose and required accuracy, which is one of the crucial factors in assessing the quality of the geodetic network.

In our case, the accuracy requirement for determining the detailed points of the columns of the bearing structure was defined:

$$\sigma_X = \sigma_Y = \sigma_Z = 0{,}005\,\mathrm{m}\,. \tag{1}$$

For determining the position accuracy of the control network we used equation for the mean coordinate error (Michalčák et al., 1983):

$$\sigma_{XY}^2 = 0{,}5 \cdot \left(\sigma_X^2 + \sigma_Y^2\right). \tag{2}$$

Assuming the mean coordinate errors σ_X and σ_Y are equal, eq. 2 can be written as follows:

$$\sigma_{XY}^2 = \sigma_X^2 = \sigma_Y^2\,. \tag{3}$$

According to (Michalčák et al., 1983), to determine the mean coordinate error $\sigma_{XY.P}$ of any point using polar method applies the following equation:

$$\sigma_{XY.P}^2 = \sigma_{XY}^2 \cdot \left[1 + \frac{s}{d} \cdot \left(\frac{s}{d} - \cos\gamma\right)\right] + \frac{1}{2} \cdot \left(\sigma_s^2 + \frac{\sigma_\gamma^2}{\rho^2} \cdot s^2\right), \tag{4}$$

where s is the distance to a detailed point; d is the distance between the points of the control network; γ is the horizontal angle; σ_s is the mean error of measured distance; σ_γ is the mean error of horizontal angle. The first component in the eq. 4 characterises the accuracy of points of the control network and the second component describes the accuracy of a point determined by the polar method. Deriving from eq. 4 we obtain the mean coordinate error of the control network point:

$$\sigma_{XY}^2 = \frac{d^2}{d^2 + s^2 - d \cdot s \cdot \cos\gamma} \cdot \left(\sigma_{XY.P}^2 - \frac{\sigma_s^2}{2} - \frac{\sigma_\gamma^2}{2 \cdot \rho^2} \cdot s^2 \right) \qquad (5)$$

In our case, we assume the maximal distance among the points of the control network $d_{\max} = 100$ m, and the maximal distance to a detailed point $s_{\max} = 50$ m. The accuracy of the employed Leica TC 407 total station is specified by the manufacturer with the mean error of measured distance $\sigma_s = 2\,\text{mm} + 2\,\text{ppm}$ and the mean error of horizontal angle $\sigma_\gamma = 2{,}0$ mgon. Substituting the specific values into the eq. 5 and considering the angle $\gamma = 0$ gon (the denominator will be minimal), the required accuracy σ_{XY} of the points of control network can be calculated. Because we assume that the observations may be affected by the various negative factors, we consider the confidence coefficient $t = 2$ and thus in the expression the required accuracy of detailed points is introduced:

$$\sigma_{XY.P} = \frac{\sigma_{required}}{t} = 0{,}0025\text{m}. \qquad (6)$$

Based on the previous analysis and substituting the specific values we calculated the accuracy of the control network point $\sigma_{XY} = 0{,}0019$ m. We therefore can conclude that the coordinates of the control network points have to be determined with accuracy $\sigma_X = \sigma_Y < 0{,}0019$ m.

Optimum design of the control network

The optimum design was realised simultaneously for outer and inner network in the PLS 2.1 software. The network was processed as a free network, the number of measured distances was 22 and the number of measured angles was 23. To calculate the optimum design, we used the D-optimum design, where the structure of measurement of the network is D-optimum (Klobušiak, 1996):

$$Det[Var(\boldsymbol{\beta}(\delta))] = \min(Det[Var(\boldsymbol{\beta}(\delta))] : \delta \in \Gamma), \qquad (7)$$

where Γ is the class of all possible designs δ for which pays $Det[Var(\boldsymbol{\beta}(\delta))] > 0$ and $Var(\boldsymbol{\beta}(\delta))$ is the global covariance matrix of the vector parameter $\boldsymbol{\beta}$ obtained by measuring according to observational design δ.

The D-optimum plan is invariant to change of the coordinate system and it means that the D-optimum design calculated in a particular coordinate system will be D-optimum also after rotating and shifting the coordinate system. It minimizes the maximum standard deviation in determining the value of directly measurable quantity in the network. The network measured according to the D-optimum observation design has in all its parts a high homogeneity of relative accuracy.

Based on the D-optimum design we obtained the number of individual nodes (angles, distances) of the network, which guaranteed the achievement of the specified accuracy criteria. As shown in tab. 1, all a priori mean coordinate errors ranged below the value 0,0019 m. Graphical representation of the network structure, the optimum number of measurements, shape and size of the standard error ellipses is shown in Fig. 3.

Tab. 1. Approximate coordinates of points and a priori mean coordinate errors.

Point	X° [m]	Y° [m]	σ_X [mm]	σ_Y [mm]
5001	1077,740	1001,140	0,96	0,82
5002	1000,000	1000,000	0,80	0,76
5003	1000,000	1105,760	1,89	1,30
5004	968,200	1043,310	1,27	1,14
5005	1015,840	964,010	0,68	0,92
6001	1051,563	1000,311	0,56	0,71
6002	1051,564	999,994	0,46	0,72
4001	1052,227	1019,270	0,53	0,90
4002	1052,256	1040,070	0,67	0,93
4003	1052,241	1082,342	1,37	1,33
4004	1014,329	1069,267	1,22	1,31
4005	1014,283	1033,208	1,00	1,04

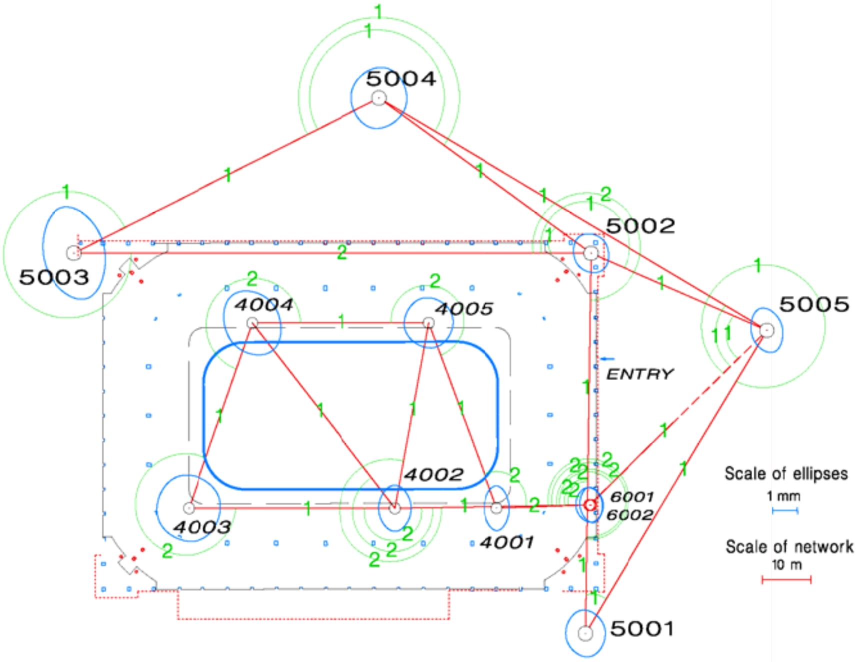

Fig. 3. Optimization of control network – number of measurements and the standard error ellipses.

After the a priori analysis we carried out the measurement which was performed according to the results of optimization. From the measurement results we estimated the coordinates of control network points and their characteristics of accuracy. In both axis X and Y the resulting mean coordinates errors ranged below 0,0015 m.

Measurement of the pillars of the bearing structure

The main part of measurements represented the pillars of the bearing construction of stadium roof, i.e. the pillars located in the outer bottom part of the stadium and inside the stadium under the roof. These measurements were necessary for determining the axial distances among the pillars. In order to determine the axial distances among the pillars, the corners of the pillars were measured using the spatial polar method and subsequently the centres of the pillars, i.e. their axis were determined. Given the appropriate layout of the points of the control network, all 4 corners of the outer pillars could be measured (Fig. 4). The pillars in the inner upper part of stadium could be measured only at two corners from inner side. These were measured from the inner control network, either directly or in the places of obscuration from the points of closed traverse connected to the inner control network. To ensure the accuracy of measurement and good identification of the corners of pillars, reflective yellow foil accompanied with a black cross was used.

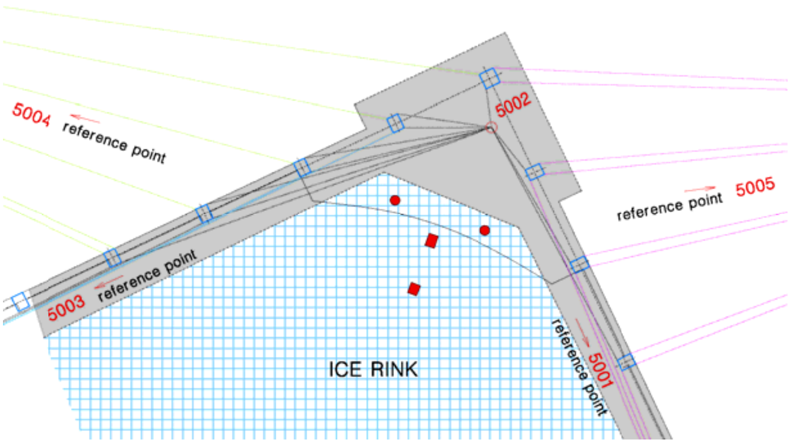

Fig. 4. Measurement of the corners of pillars.

Measurement for 3D documentation creation

Another task was measuring the existing pillars located at the corners of the stadium (red in Fig. 4). These pillars were circular and rectangular in shape and belong to the pillars of bearing structure. The access to these pillars was limited and they could be measured from the level of penultimate floor using a traverse connected to the inner control network. The round pillars were measured by three points and the rectangular pillars by four points at the corners using the reflective foil.

The largest number of detailed points formed measurement of the ice hockey ground, stands, stairs, and entry and exit areas of the stadium. To measure these points, we used the points of the inner control network, where the points were measured using the polar method or on difficulty accessible places by means of the closed and link traverses. In some cases, given the accuracy and layout of the control network points also a determination of free station to overcome various obstacles was favourable. The detailed points were measured and signalized using the reflective foil, Leica mini prism, or reflectorless under appropriate conditions. While reviewing the important detailed points by double measurement, the required accuracy 0,005 m was not exceeded. In addition to the positional measurement, it was also necessary to control the height of each floor. Due to the availability and fast measurement, the detailed points were measured trigonometrically using the Leica mini prism.

Interpretation of the results

To compare the existing documentation with the measured results, transformation of the drawings into the coordinate system of the performed measurements was needed. For this purpose we applied transformation of four points representing the centres of exterior pillars, which were obtained from the coordinates of the drawing and from intersections of measured corners. The deviations resulting from the transformation are shown in Tab. 2. For comparison the table also contains the coordinates of theoretical centre of the stadium obtained as the intersection of the axis points of the corner pillars from documentation (labelled A) and measurement (labelled O). As the table shows, the deviations obtained range in order of centimetres. The theoretical centre deviates only in the X-axis (-0,012 m), which confirms the correctness of the transformation.

Tab. 2. Deviations in coordinates of the centres of pillars after transformation.

Point	**Y** [m]	**X** [m]	**Point**	**Y** [m]	**X** [m]	**ΔY** [m]	**ΔX** [m]	**ΔP** [m]
A_1	1099,870	997,910	O_1	1099,844	997,956	0,026	0,046	**0,053**
A_2	999,040	997,789	O_2	999,050	997,811	0,010	0,022	**0,024**
A_3	998,955	1068,689	O_3	998,979	1068,644	0,024	-0,045	**0,051**
A_4	1099,785	1068,810	O_4	1099,708	1068,740	0,077	-0,070	**0,104**
$Centre_1$	1049,424	1033,296	$Centre_2$	1049,424	1033,284	0,000	-0,012	**0,012**

Subsequently, the axial distances among the adjacent pillars in the transversal and longitudinal direction of the ice rink were compared (21 transversal axis labelled from 1 to 21 and 15 longitudinal axis labelled by the letters A to O). In the transversal direction, differences in the axial distances among the longitudinal axis A to D and L to O were obtained. In the longitudinal direction, differences in the axial distances among the transversal axis 1 to 4 and 18 to 21 were found. Specific values of the deviations are given in tab. 3.

Tab. 3. Differences in the axial distances.

Longitudinal direction (axis 1 – 21)		**Transversal direction (axis A – O)**	
Label	**Difference** [m]	**Label**	**Difference** [m]
1-2	-0,148	A-B	-0,215
2-3	-0,134	B-C	-0,104
3-4	0,268	C-D	0,298
18-19	0,271	L-M	0,265
19-20	-0,128	M-N	-0,131
20-21	-0,154	N-O	-0,122

Based on the above mentioned results, for preparing the reconstruction documentation where was an assumption of continuity with the existing state of the supporting pillars of the stadium, it was necessary to take into account the actual axial distances.

Another important basis for the project was also creation of 2D and 3D documentation of the actual state inside the stadium. This processing was performed on the basis of the captured spatial coordinates of points in MicroStation software. For the purpose of the project, two longitudinal profiles and transversal profiles with height dimensions of the floors and required features were created. The resulting 3D scheme is shown in Fig. 5.

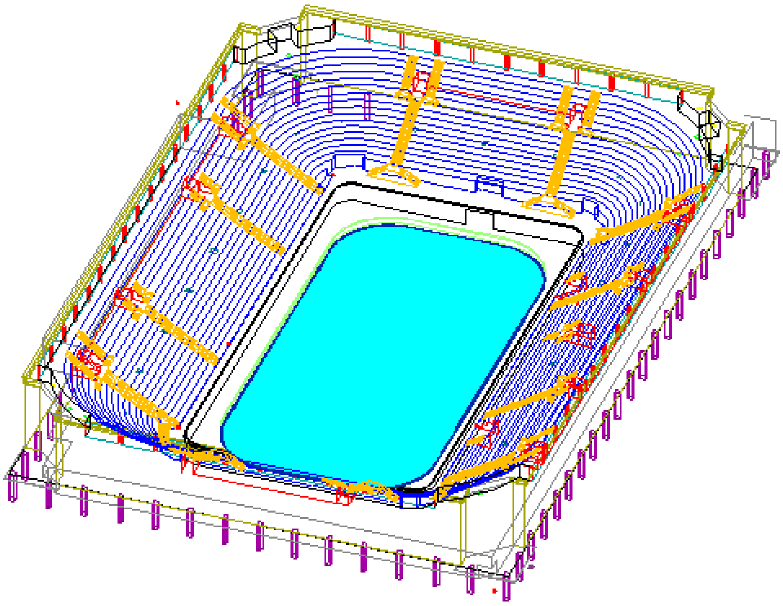

Fig. 5. 3D scheme of the actual state of the ice rink.

Conclusion

Deviations that are found in the documentation often financially exceed the costs of any adjustments as is the costingness of the surveying measurements. This was also confirmed in the case of verifying the existing documentation of the ice rink where the differences in some axial distances of the existing supporting pillars were obtained.

Surveying works have to meet high accuracy demands, which are required by the developers. In order to meet these requirements it is necessary to devote attention to establishing the control network, which forms the basis for the follow-up detailed measurement. In order to established the control network with the highest accuracy it is not often necessary to employ the instruments of the highest order of accuracy, but if we use the appropriate tools of statistics – the methods of estimation and optimization (Gašinec, Gašincová, 2005), we can achieve reliable results with instruments of the second or third order of accuracy, as it was presented in this paper. On the basis of our surveying measurements was prepared the reconstruction project and the reconstruction works on the Ice Rink of O. Nepela in Bratislava began in May 2009.

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