DEFORMATION MEASUREMENT OF THE ROOF CONSTRUCTION OF PAVILION „Z“ AT BRNO TRADE FAIR GROUNDS

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ABSTRACT

Brno Trade Fair grounds belong to the largest ones in Czech Republic. Dominating the grounds is the „Z" pavilion of circular shape, covered over by steel grill dome with 93,5 m diameter. The pavilion was built up in 1958 after design of Prof. Lederer of Brno. BUT Department of geodesy had been measuring the deformations of the roof construction in course of the maintenance works in period December 2005 – July 2006. In course of altogether 8 measuring epochs the vertical and radial deformations of the construction caused by temperature changes, snow loading, and maintenance works influences had been determined. In the contribution the measuring methods employed, and the results of 8 epochs of the deformation surveys are presented.

1. INTRODUCTION

The „Z“ pavilion at Brno Trade Fair grounds belongs to world´s most significant buildings of this kind because of its unique steel roof construction. The pavilion was built in 1958 after design of Prof. Ferdinand Lederer of Brno (1906-1990), who was founder of the czech-slovak school of slab truss and grid carrying steel systems for roofs of big span. The pavilion „Z“ has been since dominating symbol of the Brno Trade Fair grounds – see Fig. 1 and Fig. 2.

At the end of 2005 the reconstruction works to ensure waterproofness of this nearly 50 years old roof construction had begun. The works included covering of the whole roof dome with special sheeting. The measurements of shifts and deformations of the roof construction within prospective reconstruction of the original sheating were carried out by Institute of Geodesy, Brno UT. Aim of the epoch geodetic measurements was to determine the behavior of the roof carrying construction under varying loading, which was expected during reconstruction. The loading caused by snow cover was used for detection of the loading effects. Winter period 2005/2006 was characterized by large snowfalls which caused crashes and damaging of many roofs in consequence of extreme snow loading. Deformations of steel constructions also depends upon temperature changes caused by interior and/or exterior environmental influences.

The deformation measurements were realized in eight epochs from December 2005 to July 2006. The time span covered temperature changes of the construction between winter and summer periods, and also included intervals with and without snow cover together with intervals with and without coverage of the construction or intervals without and with sheeting cover.

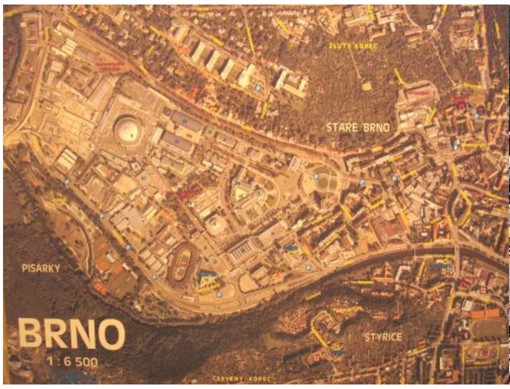


Fig. 1. Brno Fair Grounds. Fig. 2. Pavilion „Z“.

2. OBJECT OF DEFORMATION MEASUREMENTS

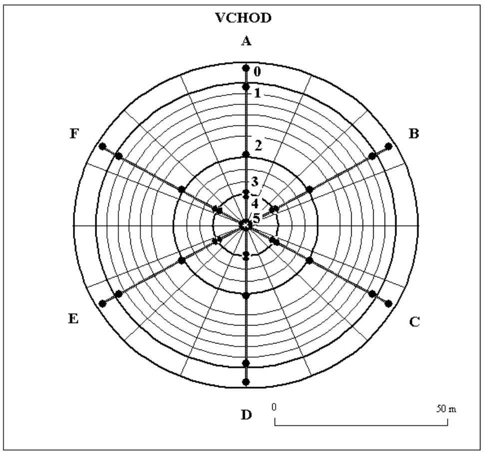
2.1 Description of the construction measured

The Pavilion „Z“ is a building of circular shape with 122 m diameter and 43 m height. Steel roof carrying construction is built as an unique circular dome-like construction with 93,5 m diameter of foot ring and 22,3 m camber (Fig. 3). Dimensions of steel tubes (continuously conducted in three vertical layers connected in knots by screwed yokes) are changing from 102/6 mm in bottom to 60/4 mm in top part (Fig. 4). Foot ring diameter is 330/17 mm. Average steel consumption on the roof construction was 33 kg m^{-2} .

Fig. 3. View of the roof construction. Fig. 4. Connecting yoke.

2.2 Selection of control and object points

The Pavilion „Z“ roof carrying construction had been represented by measured points (places) which were spread regularly in six vetical profiles and six elevation levels. The profiles are named A to F, and the points in single profiles are numbered 0 to 5, while the point 0 is at the lowest elevation level, and the point 5 is at the highest (central) level – see Fig. 5. Points of the lowest level 0 were marked at the level of foot ring on the horizontal face ring. Points of the level 1 correspond to the sixth horizontal ring (counted from below), points of level 2 correspond to the fifteenth ring. Points of level 3 correspond to the third horizontal ring counted from the central ring carrying the inner foot bridge, points of level 4 are at the edge of this central ring. Finally points of level 5 correspond to interior edge of the roof cap (Fig. 6).



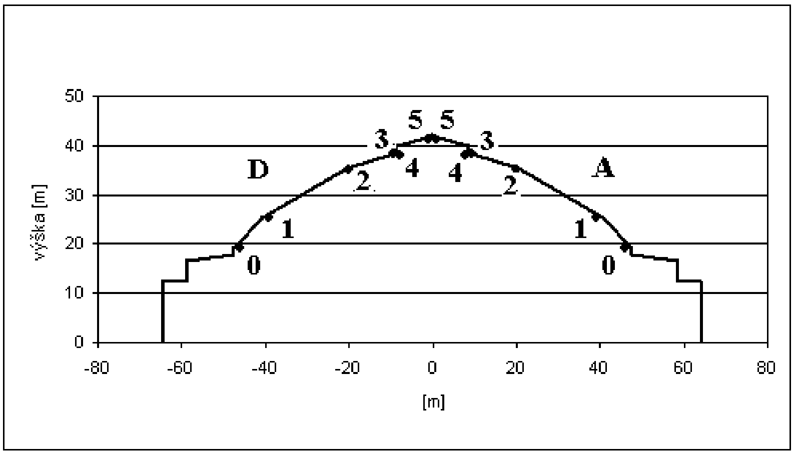


Fig. 5. Profiles and points measured. **Fig. 6. Elevation levels of profile points.**

A local coordinate system was established for detection of positional changes of the points measured. Reference point S was marked in proximity of construction central point as the origin of the local systém with coordinates X = -100,000 m , Y = -100,000 m , Z = 200,000 m. The point was placed at concrete floor of the pavilion at intersection of the principal dilatation joints. Negative direction of the X-axis was put into line going through the orientation point OSA marked in proximity of pavilion main entrance.

2.3 Measuring method

The deformation measurements were based on the 3D polar surveying method. The instrument employed was the total station TOPCON GPT-2006 enabling prismless distance measurement up to 150 m. In prismless distance measurement mode the total station uses the laser pulse distance meter with accuracy characterized by standard deviation ± 10 mm for distances up to 25 m, and ± (5 mm + 2 ppm) for distances greater than 25 m (parameters given by manufacturer).

In course of single deformation measurement epochs the total station had been centred over the point S and oriented with help of fixed orientation markers. All the monitored construction points were then repeatedly measured. During measurements the points were not specially signalized – distances were measured in prismless mode by reflections from cylindric tube surface of respective rings, always to the nearest point of the surface in direction of the instrument. Sightline of this point had been determined as an average of the directions to top and bottom edge of ring tube.

Problems of sighting accuracy by prismless distance measurements to curvilinear surfaces for the instrument used are discussed within diploma thesis (Puchrik, 2007). Results of the testing indicate high relative accuracy of the instrument on level of a few millimeters, but also the comparatively greater values of systematic errors depending upon immediate surroundings of the target point. Nevertheless, by repeated sighting of identical targets the systematic differences are suppressed to minimum.

3. MEASURING EPOCHS

To determine the positional differences between the state without loading and following states under varying loading levels it was necessary to carry out the initial epoch of deformation measurements before snowfall. This initial epoch which served as reference in relation to all following epochs had been measured on December 19th, 2005. Overview of all epochs of deformation surveys realized is shown in Table 1, together with loading and temperature data.

Table 1. Overview of pavilion „Z“ measuring epochs.

Measuring epoch	Date	Temperature [^{o} C]		Loading	
		interior	exterior	Load	[kg m^{-2}]
Initial	19.12.2005	+3	+ 1	-	0
2	29.12.2005	+1	- 4	Snow	11
3	04.01.2006	+3	+ 6	Snow	30
4	31.01.2006	-4	- 7	-	0
5	11.04.2006	+11	+ 1	-	0
6	20.06.2006	+27	+ 29	-	0
7	18.07.2006	+27	+ 29	Sarnafil sheeting	2
8	21.07.2006	+31	+ 32	Sarnafil sheeting	2

In course of each single measuring epoch the additional factors influencing behavior of the roof construction were registered; namely the thickness of snow cover, and also the interior and exterior temperature. The snow cover thickness had been estimated for single sectors and rings of the roof casing. Snow mass over 1 m^2 had been determined experimentally. Total snow loading of the construction in each individual epoch was then estimated from the average thickness of snow cover.

In each measuring epoch the interior temperature values at several pavilion places, and also the exterior temperature values. For better determination of diurnal temperature changes in time of the deformation surveys the data from permanent meteorologic station at Institute of Geodesy were also used; the data included temperature atmospheric pressure and humidity values recorded in 1 min. intervals. Maximal difference in construction temperature between subsequent epochs was over 30^{o}C (see Table 1), while in dome cap the difference amounted to more then 50^{o}C.

4. RESULTS OF THE MEASUREMENTS

Main result of the deformation measurements is the determination of vertical and radial displacements at 36 selected places (points) of the roof construction, see Fig. 5 and Fig. 6. All the displacements were related to the initial (first) measuring epoch. The results were documented in tabular and graphical outputs. Graphs of displacements were drawed for each single construction profile. Denomination of the profiles and profile points is clear from Fig. 5 and Fig. 6, where profile D is opposite to profile A, profile E is opposite to profile B, and profile F is opposite to profile C.

In following figures (Fig. 7 and Fig. 8) the vertical shifts of points in selected profile E - B in epochs with minimal and maximal temperature are shown. Fig. 7 illustrates the vertical shifts of points between initial epoch (+ 1°C) and epoch 4 (– 7°C). Fig. 8 illustrates the vertical shifts of points between initial epoch and epoch 8 (+ 32°C).

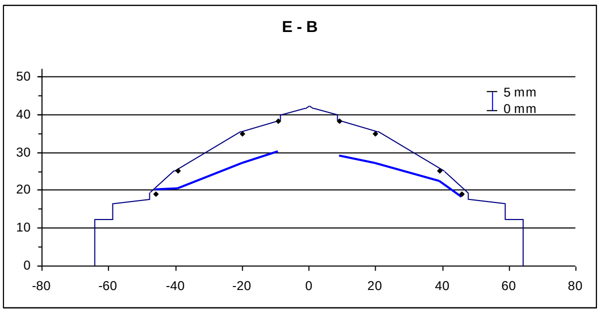


Fig. 7.Verical shifts in epoch 4 (-7°C).

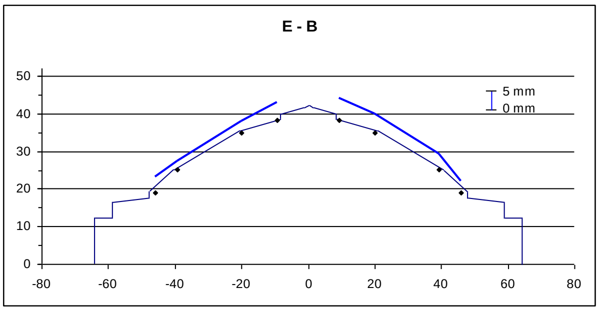


Fig. 8. Verical shifts in epoch 8 (+32°C).

In the figures the initial state (black line) and deformations in respective epochs (blue lines) are depicted. The temperature influence can be clearly seen there. This factor proved to be dominating from all the factors monitored (snow, sheeting). The radial deformations were depicted in similar way.

The vertical deformations (shifts) caused by snow cover loading are illustrated in following Table 2 and Table 3.

Table 2. Vertical shifts in epoch 2 in respect to initial epoch.

profile level	A [mm]	B [mm]	C [mm]	D [mm]	E [mm]	F [mm]
0	-1	0	-1	0	1	1
1	0	1	1	-1	-2	0
2	-1	-2	-3	-3	-4	-4
3	-3	-3	-2	0	-1	-1
4	-2	-2	-1	-3	-1	-3
5	-6	-5	-2	-1	-5	-10

Epoch 2: Snow 11 kg/m^2, temperature difference interior –2 °C, exterior -5 °C

In epoch 3 the measured snow unit mass was higher, but snow covered not the whole roof. However, it is clear from the tables how the snow cover loading influenced the vertical construction displacements which were maybe partly compensated by construction temperature changes.

Table 3. Vertical shifts in epoch 3 in respect to initial epoch.

profile	A	B	C	D	E	F
level	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
0	-1	-2	-2	0	0	2
1	-2	-6	-2	-2	-4	-2
2	-3	-4	1	-4	-3	-7
3	-4	-6	-3	-3	-2	-2
4	-4	-6	-4	-5	-2	-4
5	-18	-23	-15	-10	-15	-22

Epoch 3: Snow 30 kg/m^2, temperature difference interior 0 ^{o}C, exterior +5 ^{o}C

Influence of incremental loading caused by added sheeting was detectable from differences between measurement results in epochs 6 and 7. The differences were mostly at level of a few millimeters (from +2mm to -3mm), and were in range of errors of the measuring method employed.

5. CONCLUSIONS

Epoch deformation surveys of the Pavilion „Z“ roof construction proved its good toughness even by increased loading caused by snow cover and temperature changes. The measurements corroborated the fact that dominating for constructional shape changes was influence of temperature changes. However, the number of measured construction places was rather small (only 6 points in each of the 6 profiles) and therefore it was not possible to monitor neither the influence of irregularly spread snow cover loading of the construction, nor the influences of varying insolation on the actual construction temperature. Also the temperature differences in more elevation levels were not determined.

Measuring method employed combining angle measurements with prismless system of distance measurement proved as usable for works of similar kind. Nevertheless, very close attention must be paid to the systematic influences. Experimental employment of the laser scanning showed certain limits of the method when used in epoch deformation surveys caused by problems of exact identification of repeatedly measured places on the object monitored.

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