DIAGNOSTICS OF STEEL ROOF STRUCTURES OF SPORT STADIUMS

M. KARMAZÍNOVÁ[1*†], J. MELCHER[1] and J. LÁNÍK[1]

[1]*Faculty of Civil Engineering, Brno University of Technology, Czech Republic*

ABSTRACT

The paper deals with the diagnostics of steel roof structures of two stadiums for winter sports built in 60^{th} years of the past century. The necessity of the diagnostic has been given by the requirement to the evaluation design of these structures, which has been caused by the new situation in the field of loadings given by the validity of the European Standards in the Czech Republic from 2010 year. Due to these changes in the normative rules, in practice the existing structures are gradually subjected to the evaluation design and depending on its results to strengthening or reconstruction, respectively. This paper is focused on the diagnostics of two steel roof structures: (i) the spatial truss grid and (ii) the member structure composed of plane truss main girders, purlins and bracings. The diagnostics of these structures consisted of two parts: (i) the verification of actual dimensions of the structural members and (ii) determination and evaluation of the actual material properties of used steel. For the solution the non-destructive methods have been used for in-situ measurement. For the verification of member dimensions (thickness of hollow sections) the ultrasound methods have been used. For the indicative determination of steel strengths the modified methods based on the determination of Rockwell's hardness have been used. This paper mainly presents the results of the measurement and verification of actual dimensions of spatial truss grid hollow cross-sections, while the determination and evaluation of steel properties are not presented in detail.

Keywords: Diagnostic, steel roof structure, verification, measurement, evaluation, non-destructive method, ultrasound, actual dimensions, thickness, Rockwel's hardness, ultimate strength.

1. INTRODUCTION

Within the diagnostics of steel roof structural systems, two constructions of sport stadiums in the Czech Republic have been investigated. The first one was the winter sport stadium in the city of Olomouc and the second one was the winter sport stadium in the city of Jihlava. The main aims of the diagnostics of steel roof structures of both constructions were to verify the dimensions of members of the roof structure and to determine actual physical-mechanical properties of structural steel to use the results in the subsequent static assessment of existing structure. Regarding the possibilities given by the different structural configurations and real structural conditions, different

[*] Corresponding author: E-mail: karmazinova.m@fce.vutbr.cz

[†] Presenter: E-mail: karmazinova.m@fce.vutbr.cz

diagnostic methods have been used. In the case of the first structure, both non-destructive diagnostic in-situ, and destructive laboratory methods have been used, while in the case of the second one non-destructive diagnostic in-situ only has been used. It was given by the fact that no structural member or structural part for destructive testing could be taken from the existing roof construction.

2. DIAGNOSTICS OF STEEL ROOF STRUCTURE OF WINTER SPORT STADIUM IN OLOMOUC CITY – SPATIAL TRUSS GRID

The roof structure of the winter sport stadium in the city of Olomouc is represented by the spatial truss grid consisting of circular tube members connected by the spherical joints. The scheme of the spatial truss grid of roof structure is drawn in Fig. 1 and the illustrations of the structural system real configuration are shown in Fig. 2. This stadium construction was realized in the period of 60^{th} years of the 20^{th} century, so that the age of all load-carrying structures is almost 50 years.

The dimensions of the roof spatial truss grid are following: the width and length in the plan are 68 x 100 m and the grid height is 4 m. The non-destructive diagnostic performed in situ was mainly oriented to the measurement of thicknesses (Karmazínová et al. 2013, Láník 2012), because the roof spatial truss grid consists of hollow cross-sections, which are used both for grid members (circular tubes), and for grid connections (spherical joints).

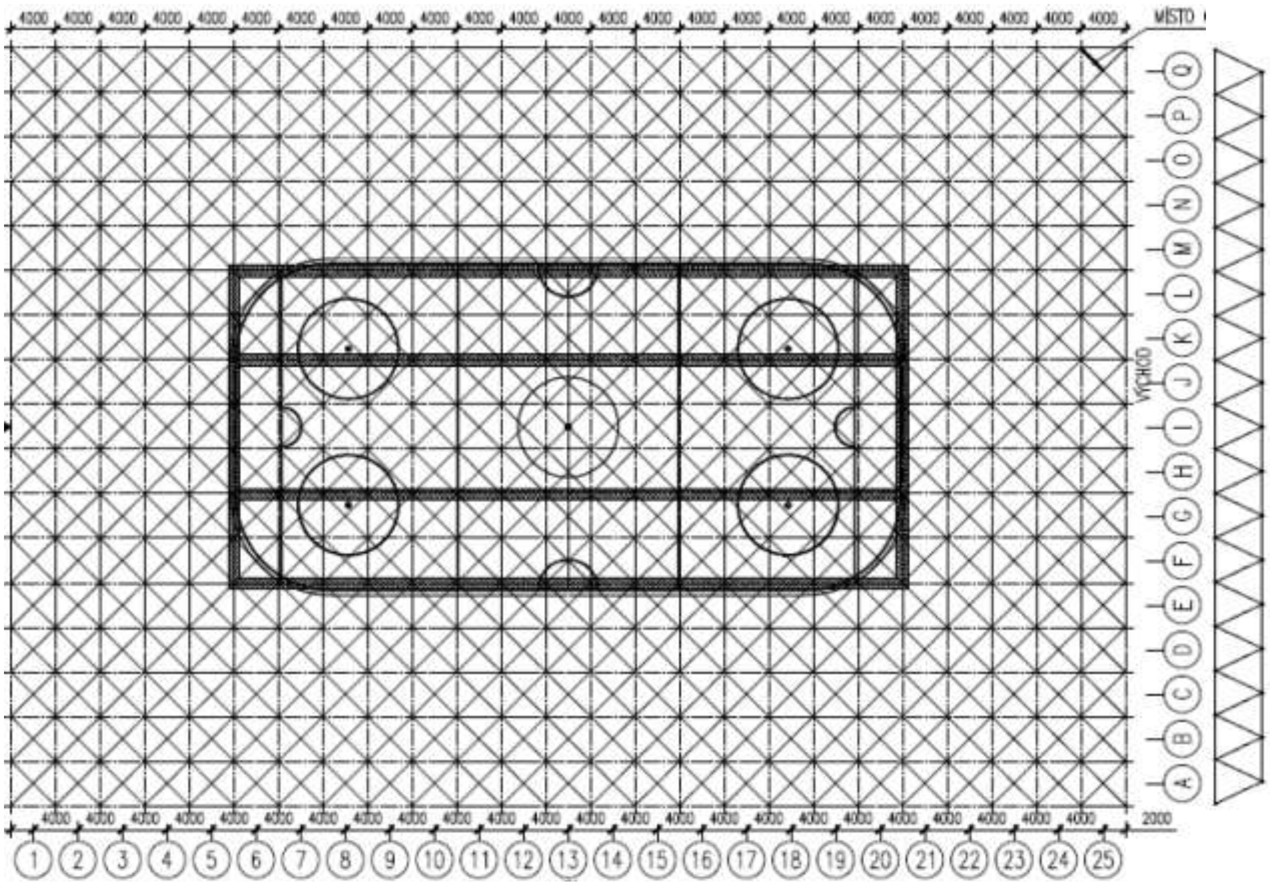

Figure 1: Winter sport stadium in Olomouc city – scheme of spatial truss grid of steel roof structure (plan and transverse section).

Figure 2: Winter sport stadium in Olomouc city – overall view and roof structural system.

2.1. In situ non-destructive diagnostic – verification of actual dimensions of spatial truss grid members using ultrasound method

Based on the client requirements, the non-destructive verification of the thicknesses of selected members of steel load-carrying roof structure has been performed at first (Láník 2012). Within this control the thickness of 29 statically significant steel members of load-carrying structure has been measured using ultrasound method. The localization of the position of verified members is specified in Fig. 3 (marked by digits from "1" to "23" and letters from "A" to "F"). Based on the preliminary static assessment, the following members have been verified: 13 tube diagonals ("1–13" in Fig. 3) with cross-sections of TR Ø 102 / 4 (7 pc.), TR Ø 127 / 6 (4 pc.), TR Ø 168 / 8 (2 pc.); 4 tube members of lower chord ("14–17") with cross-sections of TR Ø 219 / 10 (2 pc.), TR Ø 219 / 14 (2 pc.), 6 tube members of upper chord ("18–23") with cross-sections of TR Ø 127 / 6 (2 pc.), TR Ø 168 / 6 (2 pc.), TR Ø 219 / 10 (2 pc.) and 6 lower chord spherical joints ("A–F").

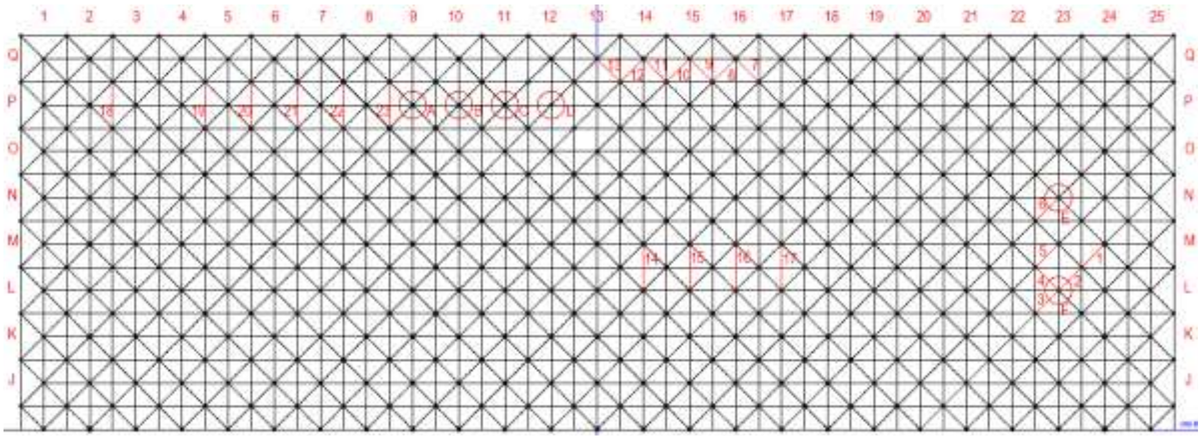

Figure 3: Localization of positions of verified tube members and spherical joints.

2.1.1. Description of ultrasound method

The measurement of the thickness of the wall of selected steel members of the roof structure was realized using the ultrasound defectoscopy instrument named "SONIC 1200 HR" by the company of "Staveley Instruments Inc. – USA". For the measurement the direct piezoelectric probe with the nominal frequency of 10 MHz; the impulse reflection method has been applied. The principle of the ultrasound method is based on the periodical mechanical oscillations, which are transmitted by the ultrasound probe to the tested material, where they are spreading by the constant speed. When the oscillations stumble upon the material non-homogeneity or upon the opposite side of tested subject, then they are reflected back with the lower energy; this process is recorded by ultrasound probe and after it is displayed on the screen of the evaluating apparatus. Time since sending ultrasound signal up to its returning back is proportional to the distance of non-homogeneity or of the opposite side. Ultrasound method is suitable for the measurement of thickness of steel structures and products.

The most accurate measurement is ensured by the probes with higher frequency, but for the usual probes with the nominal frequency of 5 MHz the reading error is about 0.3 mm. This error could be only eliminated by very high quality of material surface at the measured point, which is not usually real in practice. So it is important to measure the thickness in one point several times. Thus, the reading is more accurate, if the nominal frequency of the probe is higher. However, the usage of the probes with the higher frequency is limited by the material ability to conduct sound and by the quality of surface where the probe is touched. The thickness of the gap between the probe and material surface also very influences the accuracy of reading. On the other hand, the probes with the lower nominal frequency of $f = 4 \pm 5$ MHz are not so sensitive to the change of thickness of the gap between the probe and tested material, therefore they are mostly used for the thickness measuring. This is also in the case of our measuring, because the surface, to what the probe has been touched, was not perfectly planar. Each non-planarity of the surface under the probe is shown by four time higher error of reading. Thus, for the gap of 0.08 mm the error of reading is 0.32 mm, i.e. 0.4 mm after rounding to tenths. So that, in this case the read thickness is by 0.4 mm higher, and it can be only influenced by the better surface preparing, to obtain zero gap between the probe and material surface on the small area of the diameter of Ø 10 mm. The error of reading because of the surface non-planarity under the probe can be eliminated by the good preparation of material surface. For the calibration of ultrasound apparatus two basic gauges K1 and K2 (see Czech Standards ČSN 35 6885 and ČSN 35 6886) have been applied. The gauge K1 is made of steel with following parameters: the speed of propagation of longitudinal waves is $c_L = 5\ 920 \pm 30\ \mathrm{ms^{-1}}$, the speed of propagation of transverse waves is $c_T = 3\ 255 \pm 20\ \mathrm{ms^{-1}}$, the attenuation is $\alpha = 0.05$ dBmm, the density is $\rho = 7.85 \cdot 10^3\ \mathrm{kgm^{-3}}$. The gauge K2 is also made of steel with the same acoustic properties as the first one. This second type of the gauge is preferred in for the measuring in situ, for its smaller dimensions and weight.

2.1.2. Measurement results

On each verified member 3 measuring bases have been prepared. Before measuring the colour layers have been removed and the surface has been aligned to be the smoothest (see Fig. 4, for example). On each measuring base of the area of 30 × 30 mm, minimally 3 measurements of the wall thickness have been always performed and subsequently the mean values have been calculated.

Figure 4: Preparation of surface of measuring bases on verified members.

Illustrations of examples of verified members including measuring places are depicted in Figs. 5 and 6; the overview of the thicknesses measured is listed in Table 1; for more see (Láník 2012).

Figure 5: Examples of verified members of tube diagonals and spherical joints.

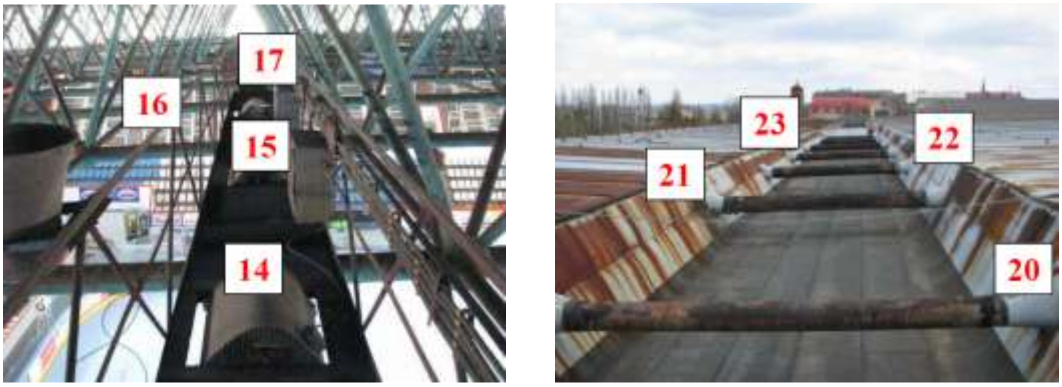

Figure 6: Examples of verified members of tube lower chords and upper chords.

Using ultrasound device "SONIC 1 200 HR", the thicknesses of the walls of selected statically important structural members of roof structure of the winter sport stadium in Olomouc city have been verified. Applying 10 MHz ultrasound probe and precise preparation of the verified members surface the measuring accuracy of ± 0.4 mm has been achieved. Based on the results of ultrasound measurement and available documentation of the roof structural system, it can be deducted, that the actual thicknesses of particular selected members, which have been measured, correspond with the thicknesses mentioned in drawing documentation.

Table 1: Measured thickness of verified members

Members marked in Fig. 2	Member type				
	tube diagonals		tube lower chords	tube upper chords	spherical joints
measured thickness t [mm] (for each member mean value of 3 measurements minimally)	1 … 6.1	7 … 5.9	14 … 10.5	18 … 6.2	A … 14.1
	2 … 3.6	8 … 6.0	15 … 10.4	19 … 5.6	B … 13.9
	3 … 3.5	9 … 3.6	16 … 14.1	20 … 6.0	C … 9.9
	4 … 3.5	10 … 3.7	17 … 14.0	21 … 5.9	D … 9.7
	5 … 3.5	11 … 7.8		22 … 10.0	E … 8.8
	6 … 3.5	12 … 7.9		23 … 10.0	F … 9.6
		13 … 6.0			

3. DIAGNOSTICS OF STEEL ROOF STRUCTURE OF WINTER SPORT STADIUM IN JIHLAVA CITY – MAIN GIRDERS, PURLINS AND BRACINGS

The roof structure of the winter sport stadium in the city of Jihlava is composed as the member structure consisting of plane girders – garland truss main roof girders with ties, parabolic truss purlins and bracing system (see Fig. 7). The construction was built at the turn of the 60^{th} and 70^{th} years of the 20^{th} century, so that the age of structures is about 40 years. The width and length of the roof structure in the plan are 60 x 100 m.

Figure 7: Winter sport stadium in Jihlava city – roof structural system.

3.1. In situ non-destructive diagnostic – determination of steel ultimate strength using indirect method based on hardness measurement

The destructive methods (Karmazínová and Melcher 2013, 2012a, 2012b) cannot be used because of impossibility to take specimens from existing structure for tensile testing, that the non-destructive diagnostics oriented to the indicative evaluation of strength is used (Karmazínová et al. 2013, Melcher et al. 2012). The standard (ISO 13822, 2005) can be applied for steel structures mentioned. Because in this case the origin material statements containing the specification of their quality were available, then the actual values of steel strengths can be assumed. For the basic verification of properties, indirect methods not requiring problematic sampling from the structure can be used (according to Brinell, Vickers or Rockwell). To determine steel strength indicatively, the method of hardness measurement can be used; the standard (ISO 13822) recommends so-called “POLDI hammer” method or other method ensuring sufficient correlation between hardness and strength.

3.1.1. Description of testing method

The “POLDI hammer” method recommended in ČSN ISO 13822 allows the fast assessment of the quality of metal materials inbuilt in the construction because of easily portable testing apparatus. The test is based on the comparison of the deformation caused by hammer in the known hardness specimen with deformation caused in unknown hardness tested material. However, from current viewpoint, this method is somewhat out of date, namely because of the fiddly and not too precise measurement of deformation size. It is especially difficult at high positions and, in addition, testing slender and hollow sections is problematic, too. According to the structure type and the elaborators experiences, the universal portable apparatus for the measurement of hardness “COMPUTEST SC” (Switzerland Company Ernst Härteprüfer SA) using modified Rockwell’s method has been chosen for testing the roof structure mentioned. The measurement is based on the exact static method enabling accurate and reliable routing of diamond edge in the measuring probe. In the measuring head the moveable sensor is placed enabling the measurement of the depth of the deformation in the range of 0-100 μm. The apparatus shows either the values of the hardness in the usual hardness units or directly tensile strength. This method is standardized by the German Standard DIN 50 157.

The aim of tests performed was to verify steel properties in various members of the roof structure. According to the documentation, the material of the purlins chords (Ve) and bracings members (Zt) is steel of the grade of 11 353 (design ultimate strength is f_{ud} = 350 MPa), as well as steel of purlins diagonals (Vd). Further, according to that documentation, the material of main truss girders chords (VP) is the same steel of the grade of 11 523 (f_{ud} = 520 MPa), while the material of tube diagonals (VT) is steel of the grade of 11 373 (f_{ud} = 370 MPa). For purlins, bracings and main girders suitable locations have been selected to be covered almost of important members for the measurement (see Fig. 8). Following total numbers of locations have been measured: 7 locations on the chords and 7 locations on diagonals of main girders, 6 locations on the chords and 2 locations on the purlins diagonals and 3 locations on the bracings.

Figure 8: Measured locations on purlin (Ve, Vd), bracing (Zt), main girder (VP, VT)

3.1.2. Measurement results

Test results have been statistically evaluated according to (EN 1990) and the characteristic values of tensile strength have been determined (see Table 2). Variation coefficient has been given v_{fu} = 0.05 (known) and fractile factors k_n have been taken from Annex D (EN 1990) for given test number.

Table 2: Characteristic values f_{uk} of steel ultimate strength

Statistical parameter	Member type			
	VP	VT	Ve, Zt	Vd
Mean value [MPa]	583	486	429	373
Standard deviation [MPa]	35.0	17.0	30.0	7.00
Variation coefficient [-]	0.05	0.05	0.05	0.05
Characteristic value f_{uk} [MPa]	521	445	376	360

Material of the roof structure consisted of truss main girders, purlins and bracings can be classified as follows: steel of main girder chords can be classified like as current steel of the grade of S 355 corresponding with steel class of 52, steel of main girder diagonals is current steel of the grade of S 235 corresponding with steel class of 37 used in the period of structure realization; steel of purlins and bracings is current steel of the grade of S 235 corresponding with steel class of 37.

4. CONCLUSIONS

Partial conclusions have been mentioned above. The paper shows the usage of indirect methods for the verification of geometrical and mechanical properties, if destructive methods cannot be applied.

5. ACKNOWLEDGMENTS

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