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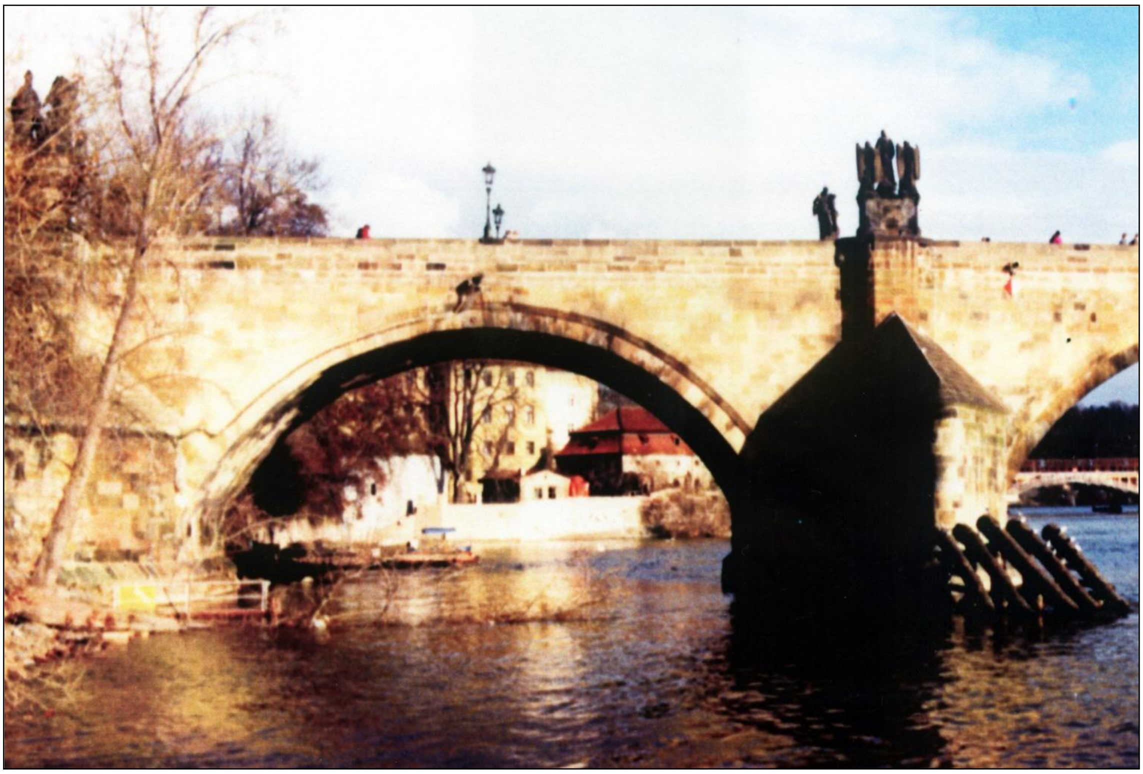
Experimental Investigation of Structures and Materials



SUMMARY

This presentation is aimed to report on experimental investigation of building structures and materials. Within thirty years, the author has conducted experimental measurements on the structures listed below.

Bridging of Masaryk‘s Railway Station	1977-78
Motorway Bridge in Velké Meziříčí	1977-79
Railway Bridge in Královské Poříčí	1980-82
Nusle Bridge	1980-81
Measurements of temperature fields of the road	
Barikádníků Bridge in Prague	1980-82
Flyover on the Spořilov connection road	1986-88
Charles Bridge in Prague	1987-90
Prague Loretto	1991-93
Measurements of the moisture content of the sculpture material	
Observatory Tower Křemešník	1993-96
Measurements of vertical gradients of wind velocity	
Nusle Bridge	1998-99
Measurements of temperature fields of a steel grid	
Nusle Bridge	2000-03
Measurements of temperature fields of a concrete structure	

The list above indicates that the measurements were mostly performed on major structures, and the author’s papers served as a basis for decision making on putting structures into operation (new bridges), or reconstruction design (Charles Bridge, a fountain with the sculpture of The Resurrection of Our Lord, Prague Loretto, Nusle Bridge – road, Nusle Bridge – structural steel grid).

Extensive and long-term measurements of temperature fields on two steel and concrete bridges (the railway bridge in Královské Poříčí, and Barikádníků Bridge in Prague) yielded source materials for the formulation of temperature loading in ČSN 73 6203 standards Temperature Loading. The experimental outcomes were, as it turned out later, employed in the design of a preliminary European standard on temperature loading ENV 1991-2-5 in an almost unchanged form.

Beside temperature and moisture measurements of bridge and building structure fields, the author has conducted long-term measurements of the vertical gradient of wind power as part of the European Community Programme, Joule II-EUROWIN, JOU2-CT92-O168: European Wind Turbine Database EUROWIN and Implementation of an European Database EUSEFTA on Wind Turbine Failures. These measurements were exploited for the prediction of the wind potential in the region of Křemešník, as well as in the whole Czech Republic. They were undertaken within international cooperation with EU countries on the development of a new science field in the Czech Republic.

SOUHRN

Přednáška je věnována experimentálním vyšetřováním stavebních konstrukcí a matriálů. Autor v časovém úseku třiceti let provedl experimentální měření na následujících stavebních konstrukcích.

Přemostění Masarykova nádraží	1977-78
Dálniční most Velké Meziříčí	1977-79
Železniční most v Královském Poříčí	1980-82
Nuselský most	1980-81
Měření teplotních polí vozovky	
Most Barikádníků v Praze	1980-82
Nadjezd na Spořilovské spojce	1986-88
Karlův most v Praze	1987-90
Pražská Loreta	1991-93
Měření vlhkostního obsahu materiálu sousoší	
Vyhlídková věž Křemešník	1993-96
Měření výškových gradientů rychlosti větru	
Nuselský most	1998-99
Měření teplotních polí ocelového roštu	
Nuselský most	2000-03
Měření teplotních polí betonové konstrukce	

Vesměs se tedy jednalo o významné objekty a autorovy práce posloužily jako poklad pro rozhodnutí o uvedení konstrukcí do provozu (nové mosty) či pro návrh rekonstrukce (Karlův most, kašna se sousoším Zmrtvýchvstání Páně, pražská Loreta, Nuselský most - vozovka, Nuselský most - nosný ocelový rošt).

Rozsáhlá a dlouhodobá měření teplotních polí na dvou ocelobetonových mostech (železniční most v Královském Poříčí, most Barikádníků v Praze) poskytla podklady pro formulaci zatížení teplotou v ČSN 73 6203 Zatížení mostů. Jak se ukázalo, experimentální vztahy byly v téměř nezměněné podobně později použity i v návrhu evropské předběžné normy pro zatížení teplotou ENV 1991-2-5.

Z měření teplotních a vlhkostních polí mostních a stavebních konstrukcí se vymykají dlouhodobá měření výškového gradientu větrné energie v rámci evropského grantu European Community Programme, Joule II-EUROWIN, JOU 2-CT92-O168: European Wind Turbine Database EUROWIN and Implemantation of an European Database EUSEFTA on Wind Turbine Failures. Měření byla podkladem pro odhad větrného potenciálu v oblasti Křemešníku a celé České republice. Jednalo se mezinárodní spolupráci v rozvoji nového vědního oboru v České republice, v rámci spolupráce se zeměmi Evropského společenství.

KEYWORDS

heat and mass transport theory, measurement of temperature fields of road and railway bridges, composite steel and concrete bridges, measurement of maximum temperature gradients in bridge structures, temperature fields, moisture fields, temperature gradients, temperature sensors, moisture sensors, Charles Bridge, Nusle Bridge in Prague, fountain with the sculpture of The Resurrection of Our Lord in the Prague Loretto, measurement of vertical gradients, wind power potential

KLÍČOVÁ SLOVA

transport tepla a hmotnosti,měření teplotních polí silničních a železničních mostů, spřažené mostní konstrukce, měření maximálních teplotních gradientů mostních konstrukcí, teplotní pole, vlhkostní pole, teplotní gradienty, teplotní čidla, vlhkostní čidla, Karlův most, Nuselský most v Praze, most barikádníků v Praze, Kašna se sousoším Zmrtvýchvstání Páně v pražské Loretě, měření výškových gradientů rychlosti větru, potenciál větrné energie

CONTENTS

FOREWORD

History of civil engineering shows that changes in temperature and moisture can have profound effects on the quality, durability and properties of building structures. The importance of the knowledge of temperature and moisture fields is growing particularly today [31], [32] when structures are generally much lighter and other building materials than the Czech construction industry traditionally exploited are being introduced.

The tendency to achieve higher efficiency of construction processes and technologies overlaps considerably with trends towards lighter structures. This tendency is materialized in two principal directions:

- the choice of a statically effective structural solution and construction technology
- the use of modern types of building materials with the required rigidity and strength parameters.

The choice of a statically effective structural solution is, to a large extent, influenced by rapid development of modern methods of structural calculations [30], [10], [2] which facilitate the use of reserves in the load-bearing capacity. However, these trends bring about certain problems which are reflected in the overall decrease in the durability and life of constructions. The reasons can be seen especially in the complex of effects of the environment on constructions. Constructions are particularly affected by temperature and moisture changes taking place in the air, solar radiation, as well as the speed of the air flowing around, for example, bridge structures. Moreover, constructions are under attack of chemical agents – aggressive components of the air, chemical treatment of road surfaces, etc.

Temperature and moisture fields unevenly distributed in sections of structures cause volume changes of material, which subsequently lead to the development of stress and strain.

If traditional, massive structures made it possible to ignore temperature and moisture effects thanks to reserves in the load-bearing capacity, modern constructions do not commonly permit such an approach. Due to the cyclic nature of the climatic impact, the additional state of stress caused by volume changes often produces microcracks in exposed places of stone or concrete structures. This situation initiates corrosion and degradation processes.

Designers of engineering structures are fully aware of this influence, but they find it difficult to assess it concretely and correctly for a lack of information about the course of changes in the gradient of temperature and moisture fields in the bridge structure under investigation. These changes take place in yearly cycles. However, even 24-hour daily cyclic changes are significant, particularly as a result of their extreme changes in shorter time periods.

This presentation describes experimental measurements of the above environmental effects on building structures, bridges in particular.

1. THEORY OF HEAT AND MASS TRANSPORT

Every physics theory is generally aimed to transform fundamental laws of nature into a mathematical form. It attempts to transform general physics ideas into a mathematical problem to be able to work with its ideas better. Thus, mathematics has become a basic medium of physics ideas. The mathematical formulation of heat and mass transport falls within non-equilibrium thermodynamics, which differs from equilibrium thermodynamics in two major directions.

The first difference lies in that equilibrium thermodynamics should be formulated as a theory of continuum, i.e. variables of state are continuous functions of space and time. This approach is reflected in the formulation of basic equations, which have so called the local form, link variables for a volume element at a given point and time. Thus, the mathematical formulation demands a certain area in which variables and local equations are defined and for which both boundary and initial conditions characterizing heat and mass transport are defined. Equilibrium thermodynamics does not require a local formulation, as variables of state are independent of space coordinates in case of equilibrium.

The second difference lies in laws of physics, the balance equation for enthropy in particular. The starting point for the generation of a physical model of heat and mass transport are fundamental laws of thermodynamics: conservation of mass principle, conservation of momentum principle, law of conservation of the moment of momentum and energy (the 1st law of thermodynamics) and the law of the balance of enthropy (the 2nd law of thermodynamics), formulated in a local form. The latter law plays a key role in non-equilibrium thermodynamics. It determines that enthropy changes in a given place for two reasons; first, as a result of the flow of the surrounding volume elements, and second, enthropy can be produced in a given place by energy dissipation. Enthropy production is always non-negative, since enthropy can only arise, it never disappears. In an idealized case of equilibrium thermodynamics, enthropy production is considered as zero.

In contrast to equilibrium thermodynamics, non-equilibrium thermodynamics also requires that the source of enthropy is expressed as dissipation of non-equilibrium processes that occur within the assumed system. Here, the hypothesis of a local equilibrium comes into play. Though it does not apply generally, it does apply to heat and mass transport. The principle of a local equilibrium suggests that the source of enthropy can be described using Gibbs's thermodynamic relation, which expresses the speed of change of enthropy in a given place by a combination of a local equilibrium balance of enthropy and the conservation of mass, monumentum and energy principle.

Differential balance equations are just a part of mathematical formulations describing heat and mass transport. To gain a functioning model of heat and mass transport, it is necessary to add material relations to the set of balance equations. These relations describe causes and effects of the heat transport process in a concrete material.

Here, it is necessary to note that the generation of transport equations is closely connected with a physical experiment. What needs to be done includes determination of material constants to be used in transport equations, as well as determination of both initial and boundary conditions and time courses of both temperature and moisture fields. This experimental field is obviously extensive, and particularly demanding to put into practice as concerns building structures. This area of experimental physics, described in the following text, is the core of this presentation.

2. INVESTIGATION OF TRANSPORT PHENOMENA IN THE FIELD OF BUILDING MATERIALS AND BRIDGE STRUCTURES

The importance of investigation of transport phenomena in the field of building materials and bridge structures currently requires formulation of physical and material laws to be added to the engineering theory.

This goal can be achieved using mathematical and physical models of building structures, which brings about demands on the cooperation of theory, information technology and experiment.

Nowadays, there are several mathematical and physical models for mass and heat transport to be applied to building structures.

2.1. Bažant‘s Model

Bažant‘s Model was generated at the Northwestern University, USA, on the basis of a large number of experiments for conditions of drying out of concrete. The model is interesting in that it attempts to show the effect of hydration processes on the moisture distribution in concrete elements. It is mathematically simpler, and therefore, more easily accessible for the construction practitioners. Its disadvantage is its application to a single material. Also, it is necessary to determine both the initial and boundary conditions for transport equations experimentally.

2.2. Lykov‘s Model

Lykov‘s Model emerges from the conservation of mass and energy principle, while respecting phase changes. Here, moisture content is expressed by means of the relation of mass of all water in the form of vapour and the liquid to the unit of volume related to the mass of porous material in dry state with respect to the same volume. The system of transport equations with boundary conditions makes it possible to determine the current distribution of the moisture and temperature field, while respecting phase changes. Due to complicated differential transport equations, it is difficult to deploy it in the construction industry.

2.3. Kiessl‘s Model

Kiessl‘s Model was designed at Fraunhofer‘s Institute of Structural Physics, Germany, and it is currently one of the practically best designed models. With a view to its application to civil engineering, the model is a step forward, given that it is obviously a technical solution compared to the physical approach of Lykov’s Model. In spite of this fact, it is clear that it still remains complicated for the technical construction practice due to its mathematical demands and dependence on experimental measurements for the determination of input data.

2.4. Sandberg – Erlandsson’s Model

Sandberg – Erlandsson‘s Model was created in Sweden for the determination of moisture of lightweight, easily moistening concrete (porous concrete, gas concrete). Its concept is close to Bažant’s Model.

2.5. Häupl‘s Model

Häupl‘s Model formulates transport equations simultaneously for water and water vapour in the area of mass transport, and it assumes their mutual conversion (water – vapour) based on sorption and disorption isotherms. Despite considerable experimental demands of the input and boundary data, as well as input parameters in transport equations, it is beneficial for civil engineering.

All the models currently exploited are designed with the assumption of simultaneous solution of transport equations for mass and heat transport. The key question for every author is the method of introducing experimentally determined boundary and initial conditions and other material relations in transport differential equations from experimental measurements, with respect to mutual interaction of temperature, moisture and stress fields with moisture phase changes. The current research focuses on this area, and this experimental part makes one of the major outcomes of the author’s investigation.

3. PRACTICAL ISSUES IN BRIDGE DESIGN

The correct determination of the loading of the bridge structure is one of the decisive problems in bridge design. While traffic load is being investigated in detail, traffic flows on roads are monitored and railway carriages are weighed, climatic loads have not been explored in such a detailed manner yet. Only a few measurements of temperature fields conducted abroad are known (see bibliography).

The author together with Prof. Ing. Jiří Studnička, DrSc. [11], [27] have been the first in the Czech Republic to install measuring sensors for the measurement of vertical gradients of temperature fields in concrete slabs of two major concrete and steel bridges – the road Barikádníků Bridge in Prague and the railway bridge in Královské Poříčí near Sokolov. Thus, they gained source data which were used by the designer of the ČSN 73 6203 standard (Ing. J. Šedivec, CSc.) in 1986 for the determination of temperature distribution schemes in this type of the bridge.

It is a favourable fact that also the European preliminary standard for temperature load ENV 1991-2-5 exploits provisions similar to ČSN for temperature on bridges, supported, among others, by experimental measurements of the author.

It remains to be said that climatic changes of the surrounding environment of structures are generally known and they are easy to measure experimentally. In contrast, measurements of temperature fields and temperature gradients inside the structure, e.g. a bridge structure, are very difficult. The bridge structures are often large, and the measurements are commonly conducted in places hard to access. Given the nature of the matter, the measurements are always long-term, and universally demanding.

The determination of gradients of temperature and moisture fields from surface temperatures and temperatures of the surrounding environment is not sufficient for the analysis of building structures. It can be misleading. It is necessary to gather data inside the structure experimentally. It is important to penetrate into the mass of the structure and determine the values inside the structure experimentally. It is also one of the key contributions of the author of the presentation in the following experiments conducted on building structures.

4. KRÁLOVSKÉ POŘÍČÍ – TEMPERATURE FIELD MEASUREMENT

4.1. Introduction

In designing composite steel and concrete bridges [11], [27] (a steel beam connected with a reinforced concrete slab), engineers should consider non-uniform increase of temperature in the bridge cross section. The temperature increase results from different thermal conductivity and thickness of both materials, different sun exposure levels in both parts of the structure, and different conditions of temperature decrease due to the flowing air. Differences in temperature, which may vary greatly in individual bridges due to specific conditions, were assumed to be 15°C by the old Czech Load Bridge Code ČSN 73 2089. This value indicated to what extent the deck can be warmer (colder) than the steel beam. Temperature variations were very strongly idealized by being considered constant through the entire depth of the beam and thickness of the deck. The situation when the steel beam is warmer than the concrete deck (which usually occurs on sunny afternoons when the beam is exposed to sunshine) is unfavourable for stresses in the reinforced concrete deck. It is due to the fact that tensile stresses from temperature add to tensions from concrete creep.

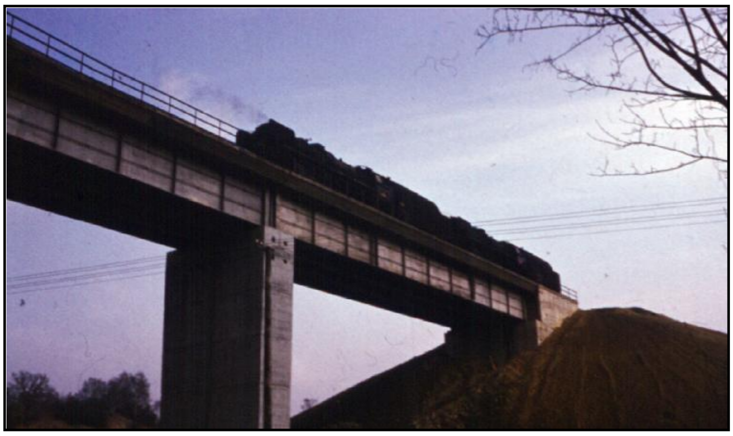


Fig.1: Railway bridge in Královské Poříčí

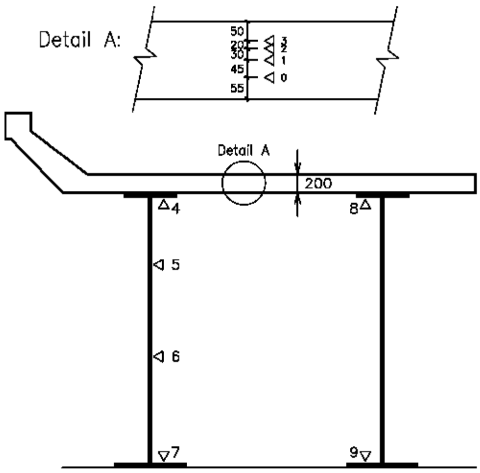


Fig.2: Placement of sensors

4.2. Measurement Results

Measurement results [19] are presented in a graphical form. Besides, maximum gradients of the temperature field are plotted by the section.

4.3. Calculated Stresses

Stresses induced in the structural section of the bridge can be deduced from the observed temperature variations.

Comparison of normal stresses suggests that, in the winter season, the highest stresses in the concrete deck caused by the temperature measured by the author were lower than the stresses caused by the temperature drop in the deck by 10°C, according to the exemption from ČSN 73 2089 (1.02 MPa < 10/15*1.97=1.31 MPa) of the Federal Ministry of Transport for bridges in Královské Poříčí. The author's measurements in the summer season proved that the temperature gradient through the depth of the beam was nearly linear. Therefore, the normal stresses in a simple beam were negligible.

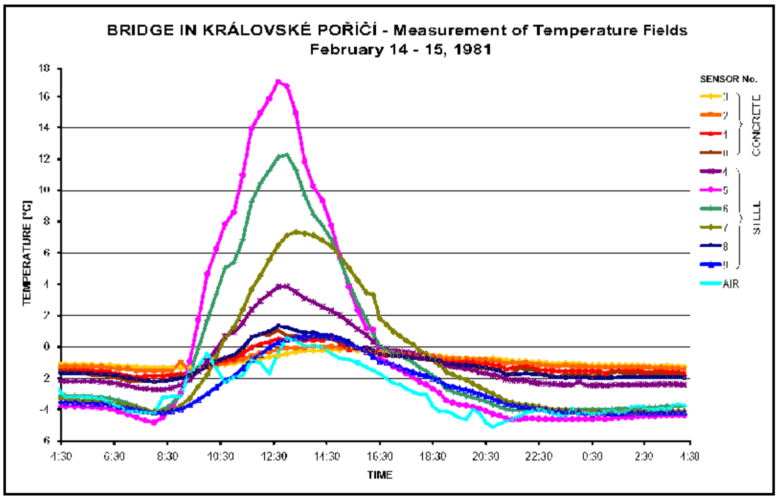


Fig.3: Measurement of Temperature Fields

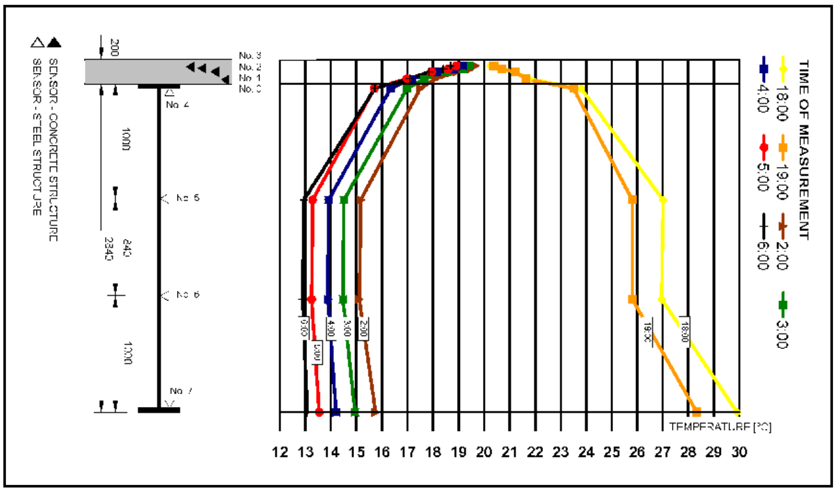


Fig.4: Measurement of Temperature Gradients

4.4. Assessment and Conclusion

The temperature measurements were conducted on the bridge in Královské Poříčí both in the summer and winter season. Although the measurements did not record the most unfavourable temperature variations in the structural steel and concrete section of the bridge, the values measured can be considered as values close to these extremes as the measurements were performed during days with considerable temperature variations under direct exposure to sunshine.

The measured values suggest that:

- the temperatures fluctuation through the depth of the section is general and it does not come close to the simplified assumptions of most standards for the design of composite steel and concrete bridges

- the temperature fluctuation through the depth of the concrete deck can be considered as linear
- the highest measured difference between the temperature of a certain part of the concrete deck and a part of the steel beam was –15.33°C or +5.62°C in summer, and –17.13°C, or +3.5°C in winter. (The minus sign indicates that the deck is colder, while plus means that the deck is warmer than the beam.)
- the measured values do not correspond to theoretical calculations very much. This disagreement can be explained by a significant effect of the gravel bed in insulating the upper surface of the concrete deck
- the measured temperature fluctuations roughly correspond to the results achieved by Severin and Barbre, as well as Pittner. On the contrary, variations measured by Badoux were not confirmed.

The above measurements and calculation results indicate that the exemption from ČSN 73 2089 principles on the temperature gradient corresponds to the real conditions of the bridge in Královské Poříčí.

5. BARIKÁDNÍKŮ BRIDGE

5.1. Introduction

The aim of the study was to continue the earlier measurements made on the bridge in Královské Poříčí and collect data on the real temperature field fluctuation and maximum temperature gradients in another large bridge structure in the Czech Republic during different year seasons.

Fig.5: Barikádníků Bridge

5.2. Measurement Results

Measurement results [16] of both the temperature field and the temperature gradients are presented in a graphical form.

5.3. Assessment and Conclusion

The results obtained on the Barikádníků Bridge can be summarized as follows:

- the temperature fluctuations through the depth of the section are general and do not compare well with the simplified assumptions of most standards for the design of composite steel and concrete bridges

- the temperature fluctuations through the depth of the concrete deck can be considered as linear
- the largest measured difference between steel and concrete in summer is -6.3°C, or +8.5°C. (The minus sign indicates that the deck is colder, while a plus suggests that the deck is warmer than the beam).

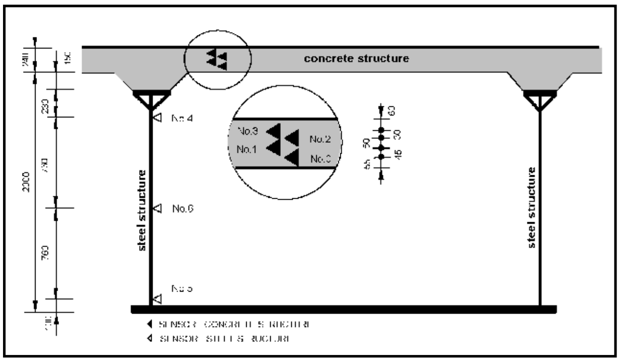


Fig.6: Placement of temperature

The first two points agree with the conclusions made regarding the railway bridge in Královské Poříčí. The third point shows that the temperature differences in the road Barikádníků Bridge were lower than in the bridge in Královské Poříčí. This finding is surprising because the comment above regarding the gravel bed suggests the opposite. However, it is also possible that the measurements conducted on the road Barikádníků Bridge did not record such extreme climatic fluctuations as the earlier measurements performed on the bridge in Královské Poříčí the previous year.

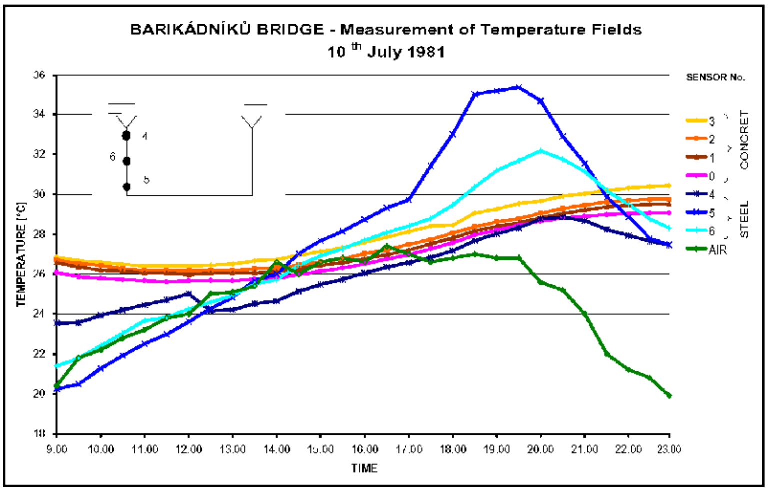


Fig.7: Temperature fluctuations

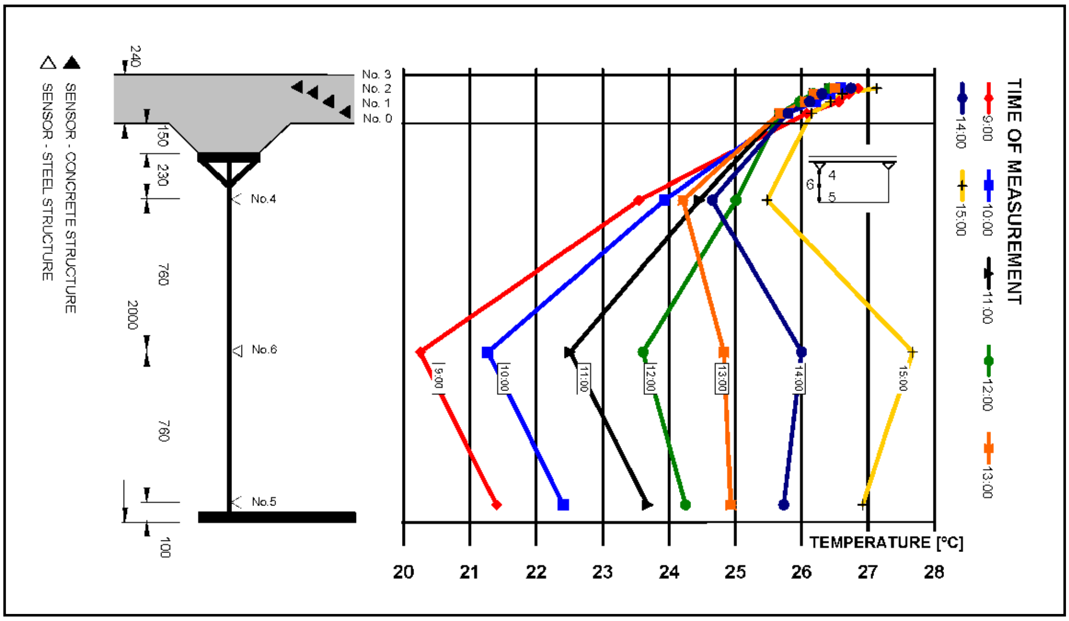


Fig.8: Temperature gradients

6. NUSLE BRIDGE – TEMPERATURE FIELD MEASUREMENT

- Measurement of temperature fields of the road *1980-81*
- Measurement of temperature fields of the structural steel grid *1998-99*
- Measurement of temperature fields of the concrete structure *2000-03*

Fig.9: Nusle Bridge in Prague

6.1. Bridge Description

The Nusle Bridge across the Nusle Valley is the largest Czech bridge structure built from prestressed concrete. Its construction was completed in 1973 to become a part of a major town artery.

The bridge structure is 485 m long and it is divided into five spans: 68.25 + 3x115.50 + 68.25 m. Structurally, it is a multiple frame. The horizontal structure is made by a massive hollow tube from prestressed concrete. The piers divided into four columns from reinforced concrete are flexible enough to facilitate horizontal displacements resulting from the dilatation of the bridge structure.

6.2. Measurement of Temperature Fields of the Road

The measurements [14], [9] were brought about by the damage of the bridge floor which was a threat to the safety of traffic. Degradation processes in the bridge road caused development of bulges which were exposed to climatic effects.

Measurement of temperature fields of the road was a decisive factor in the analysis of causes of the development of degradation processes in the road.

The results of the measurement were used as data for the reconstruction of the bridge floor of the Nusle Bridge.

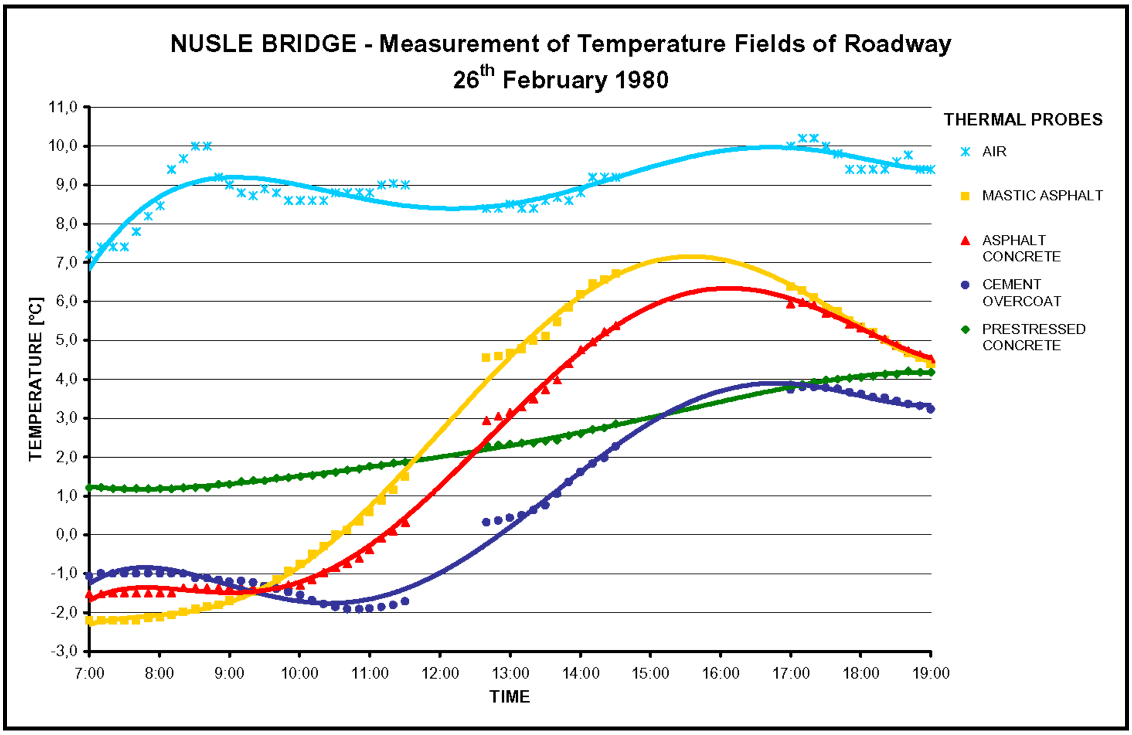


Fig.10: Measurement of temperature fields of the road

6.3. Measurement of Temperature Fields of the Structural Steel Grid

Fig.11: Fatigue cracks in the steel grid

The site inspection of the steel grid of the Nusle Bridge in Prague conducted from December 1997 till January 1998 revealed fatigue cracks.

The fatigue damage of the steel grid of the Nusle Bridge in Prague was a serious fault which unfavourably affected its load-bearing capacity and, at the same time, put at risk its further durability and serviceability. It was a serious problem, the more so because the Nusle Bridge not only represents a key node in the Prague traffic, but it also is a continuation of the D1 motorway in Prague. Therefore, due measures were taken immediately, and the steel grid was subjected to regular inspections till the final completion of the reconstruction. The measurement of temperature fields [18] of the structural steel grid was part of a diagnostic survey which was used in the preparation and conduct of the final reconstruction of the steel grid.

6.3.1. Bridge Structure and Placing of Temperature Sensors

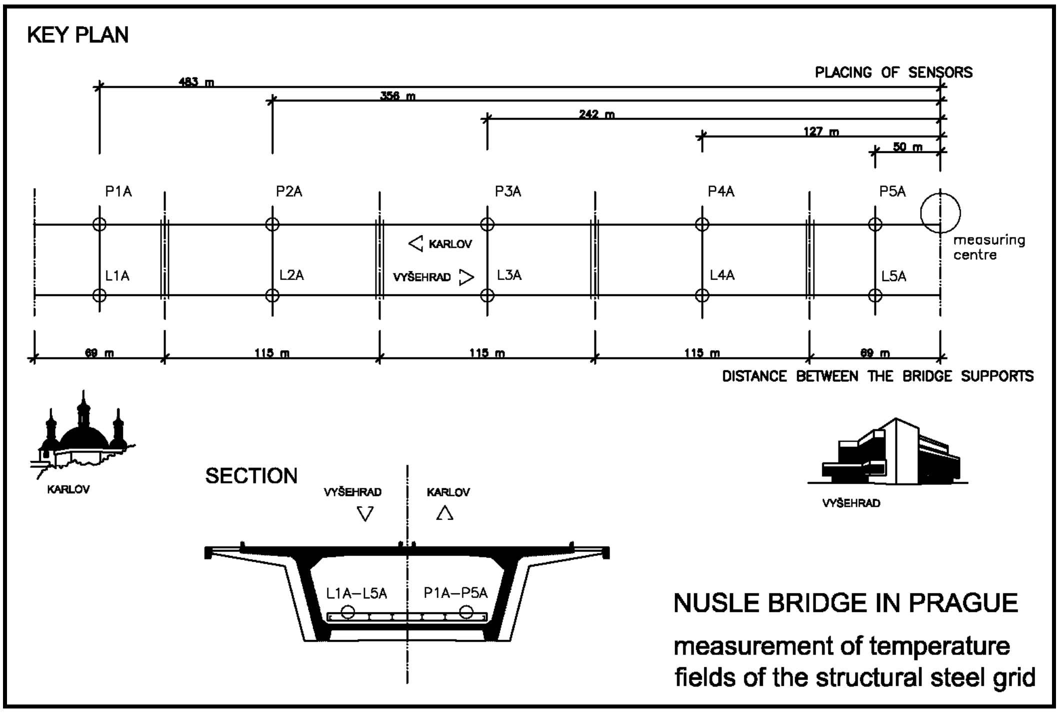


Fig.12: Bridge structure

6.4. Measurement Results

The results of the measurements of temperature fields of the structural steel grid performed between May 11 – 18, 2000 were selected from the entire database of experimental data [16], [17] to be included in this presentation.

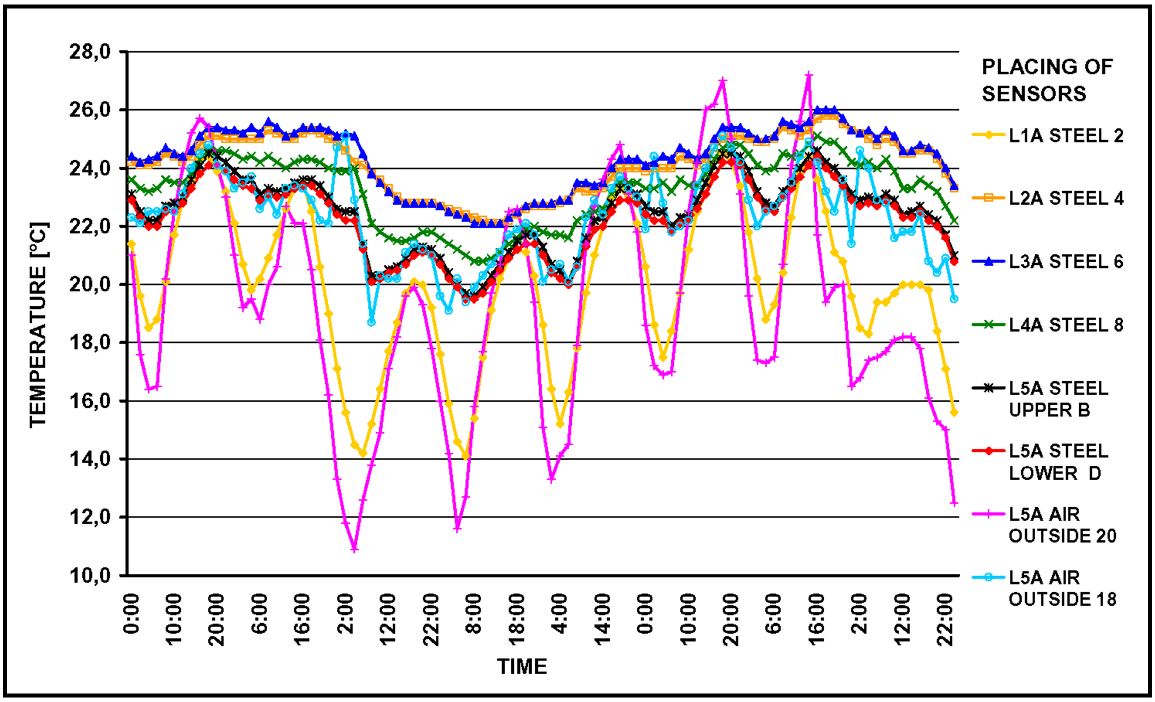


Fig.13: Measurement of temperature fields of the structural steel grid

6.5. Measurement of Temperature Fields of a Concrete Structure

Viewing the necessity to solve the problem of fatigue cracks in the structural steel grid of the Nusle Bridge, a general analysis of the state of damage of the steel structure of the grid was made. Based on its outcomes [21], a solution was proposed to secure a long-term durability and safe operability of the steel grid of the Nusle Bridge.

This development actually opened discussions on the condition of the prestressed concrete structure of the bridge itself.

This issue was treated by means of the measurements of temperature fields of the concrete structure of the Nusle Bridge.

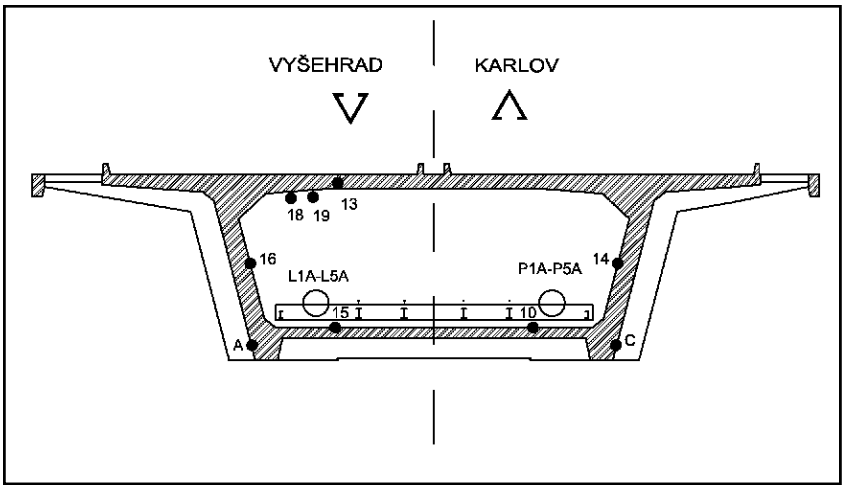


Fig.14: Placing of temperature sensors

6.6. Measurement Results

Out of the entire database of experimental data, the results of the measurements of temperature fields of the concrete structure performed between January 24 – 27, 2000 were selected.

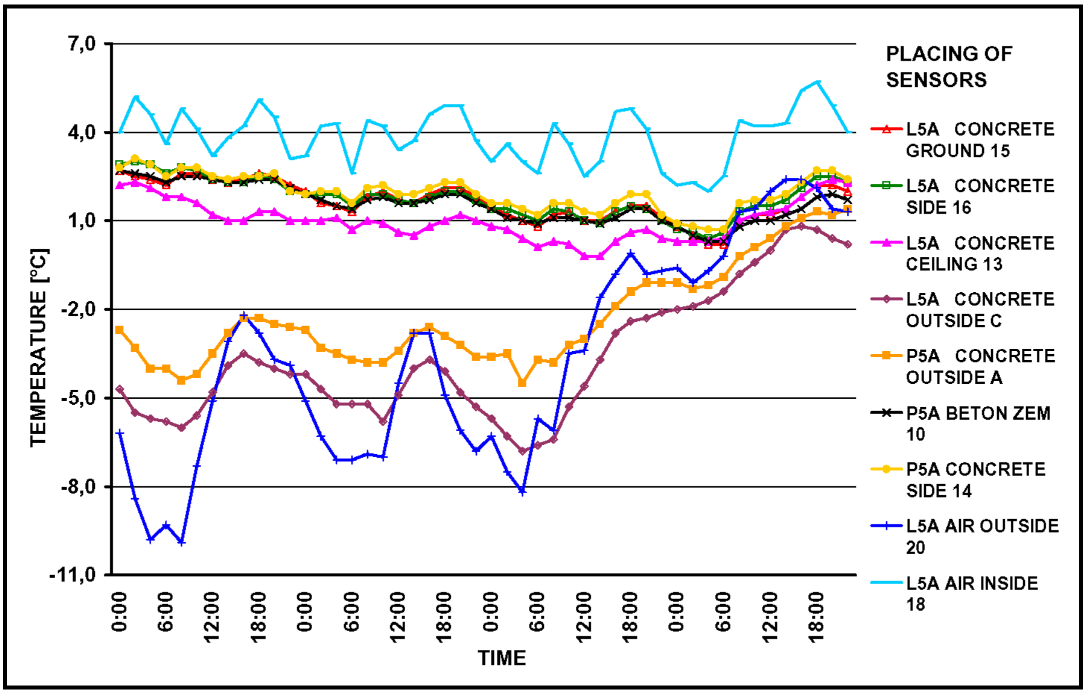


Fig.15: Measurement of temperature fields of the concrete structure

7. CHARLES BRIDGE – TEMPERATURE AND MOISTURE FIELD MEASUREMENT

7.1. Introduction

In connection with preparatory works on the planned, future general reconstruction of Charles Bridge in Prague, measurements of temperature and moisture fields of the structure of Charles Bridge were conducted.

Viewing the location of bridge arch XI in the vicinity of arches VIII, IX and X, assumed for urgent reconstruction, arch XI was initially suggested for the temperature field measurement. Another reason for its selection was its easy accessibility from the riverbank. However, operation of the stone works situated close to this arch, and even more so the forge with a furnace could affect the temperature field unfavourably. Therefore, further discussions proposed arch X located near the riverbank, above the water level. It was one of the arches with the highest measured deformations.

7.2. Brief History

Prague's oldest bridge belongs to the most beautiful bridges world-wide. It was originally named Prague or Stone Bridge, and it received its current name, Charles Bridge, as late as in 1870. A Romanesque bridge, called Judith's Bridge, had initially been situated in its place, built in 1158 - 1171. In 1272, it was seriously damaged by a flood and in 1342 an onrush of ice, wood and other material pulled it down. The bridge destruction was considered a national disaster in its time.

Fig.16: Charles Bridge in Prague

After this catastrophe, only a temporary wooden bridge was provisionally used for an extended period of time. King Charles IV (1346 - 1378) laid the cornerstone of the new bridge at 5.31 a.m. on July 9, 1357. The date and exact time were selected with respect to the conjunction of the Sun and Saturn, which was, according to astrologists, the most suitable and fortunate moment of the year for an event of this significance. The bridge construction, entrusted to a young architect Peter Parléř and his iron works, was completed in 1406.

The bridge has 16 compartments with a clear span of 16.62 m near the Old Town's Bridge Tower and 23.38 m at the Lesser Town's Bridge Tower. The bridge layout is slightly elongated, S-shaped. Its length is 515.76 m and its width is 9.4 m. Built of sandstone blocks and enclosed by entrance gates with towers, it rests on 16 massive piers. The Old Town's Bridge Tower was also erected by Parléř´s iron works, while the Lesser Town's Bridge Towers date back to different time periods, respectively.

There are 30 statues and statuaries of saints standing on the bridge rail. They were created by major Baroque artists.

7.3. Bridge Reconstruction

The latest major reconstruction of Charles Bridge was undertaken in 1966 - 1976. The capital repair included the following:

- extensive replacement of damaged sandstone blocks
- extraction of debris from the inside of the bridge structure
- stabilization of arenaceous marl above its arches by grouting
- reinforcement of the entire bridge structure with a reinforced concrete slab anchored to flank walls of the bridge.

It mainly aimed at preventing spandrel walls above piers carrying the statuary from tilting. The reinforced concrete slab was designed by Academic Bechyně [1].

A layer of lightweight aggregate concrete (LWAC) was placed on the reinforced concrete slab to serve as thermal insulation. Further, concrete screed, asphalt insulation, cement mortar and granite paving were laid in the mortar bed.

Following its reconstruction, Charles Bridge as a major historical monument was subject to monitoring. The activities listed below were undertaken:

- measurement of horizontal displacements between spandrels
- measurement of displacements and cracks
- monitoring of vertical displacements.

It was at this time that cracks in spandrel walls were discovered and cracks origination in bridge arches was observed. Measurement of cracks development proved that dilatation and closing of cracks were related to temperature changes in the structure. The cracks development depended on temperature changes occurring during seasons of the year. The cracks were closing at high summer temperatures, at winter temperatures they were opening.

The basic impact of the temperature field was enhanced by moisture field effect. As a result, the dilatation of the bridge structure cracks in places where the insulation function failed and the arch was soaked turned out to be five times higher compared to the dry arch.

Moreover, the site investigation [28], [29] revealed that both the inside of the bridge and the stones in its walls were saturated with salt, coming from long-term winter gritting of the pavement when salty water used to leak into the bridge structure. Salt acts so that it binds with water, thus increasing the moisture of the entire bridge structure.

The above were the main reasons for initiating experimental measurements of extreme changes of temperature and moisture fields of Charles Bridge.

7.4. Description of the Bridge Structure

For the measurement of temperature fields in Arch X of Charles Bridge, two places were selected for the placing of temperature sensors in the longitudinal axis of the bridge, including:

- point A with borehole S1 (see Fig. 17) at the bridge pier
- point B with borehole S2 (see Fig. 17) at the crown of the bridge arch.

(The plan to drill borehole S2 was abandoned as individual bores made it possible to examine the structure of the layers above the arch as well as their structural materials sufficiently.)

Core holes with core recovery were conducted in the marked places to the specified depths on site. The drilling diameters for placing temperature sensors were 56 mm; in case of borehole S1 they were 112 mm.

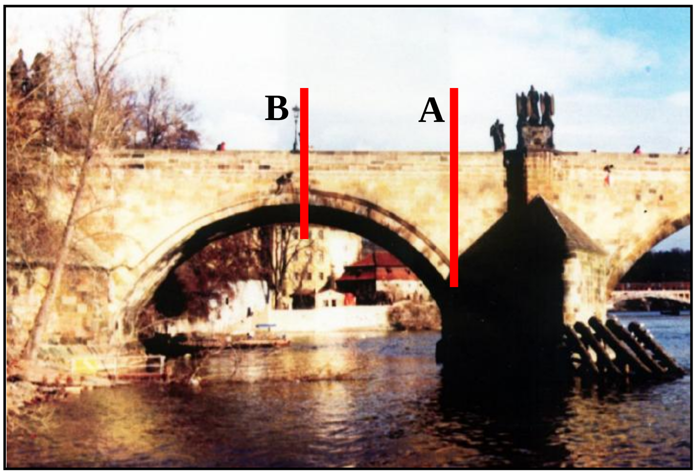


Fig.17: Charles Bridge – arch X

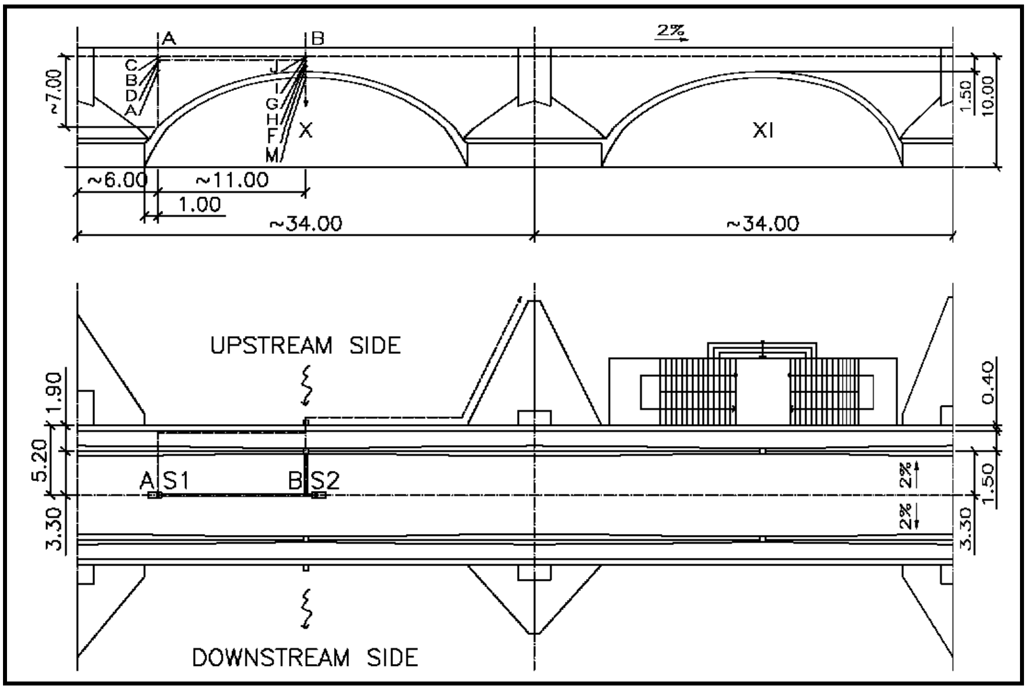


Fig.18: Charles Bridge - layout and longitudinal section

Fig. 17 and 18 show the location of temperature and moisture sensors. At point A - pier, four boreholes were made with a diameter of 56 mm; one borehole (S1) was made with a diameter of 112 mm. Four boreholes with a diameter of 56 mm were also made at point B - arch. Table 1 presents detailed information.

Fig.19: Drilling of boreholes in Charles Bridge

Point A - Pier		
A	Loose material	J - 1 – 232
B	LWAC	J - 2 - 65
C	Cement mortar	J - 3 - 12,5
D	Reinforced concrete slab	J - 4 – 75
S_1		J - 5 - 210
Point B - Arch		
F	Sandstone (extrados of the arch)	J - 1 - 110
G	LWAC	J - 2 - 65
H	Reinforced concrete slab	J - 3 - 65
I	Cement mortar	J - 4 - 12,5

Tab. 1: Marking of the core holes

7.5. Measuring Methods and the Measuring System

The selected measuring methods [15], [20], [8] required that measurements were conducted in 24-hour cycles in different year seasons to facilitate objective determination of the effect of temperature changes on the bridge structure.

7.5.1. Temperature Sensors

New temperature sensors were developed specifically for the measurement of temperature fields in the Charles Bridge structure.

For the measurements, the four-wire method of temperature measurement with platinum sensors Pt 100 Ω was finally selected.

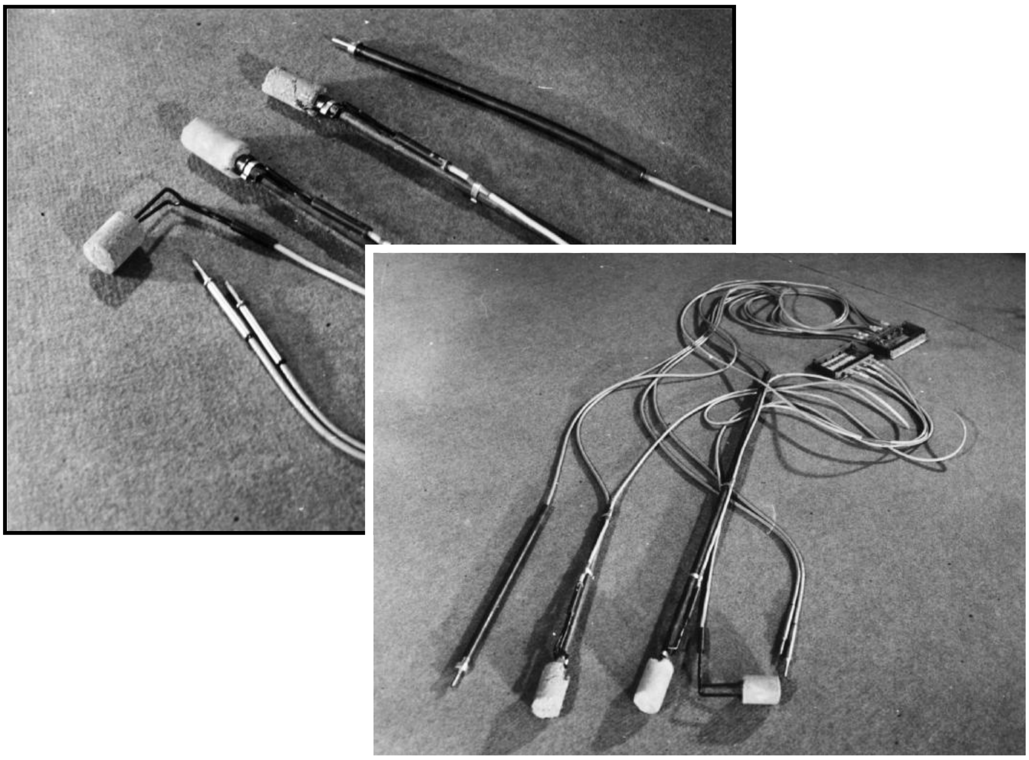


Fig.20: Temperature sensors

Each produced sensor was calibrated in the laboratory, and calibration constants were determined to facilitate computer control of the whole experiment.

7.5.2. Placing of Temperature Sensors in the Bridge Structure

The demands on quality and speed of works on a major historical monument are high. Therefore, the author carried out preparation works related to the placement of the temperature sensors in the bridge structure in laboratories of the Faculty of Civil Engineering, Czech Technical University in Prague, beforehand.

In order to achieve maximum possible contact of the temperature sensor with the original material, the measuring parts of the temperature sensors were fitted with laboratory made rollers of the original material (see photo documentation).

The sensors modified in this way were placed in the bores of an approximately identical diameter in the bridge structure. The bore depths were selected so that the sensors could be laid approximately in the middle of the thickness of the measured layer.

Further, the temperature sensors were fitted with a protective tube for the cable line. At the same time, the protective tubes enabled placement of the measuring sensors precisely at the required depth of the structure.

The temperature sensors with the protective tube were then sunk into the bores and sealed with the original material. In addition, they received insulation and waterproofing.

The cables of the temperature sensors were led into the working spaces A - pier and B - arch, and connected with the cable line leading from the measuring centre. Fig. 20 shows the temperature sensors, the temperature sensors in the protective tube and the temperature sensors with the rollers made of the original material.

The following table presents basic information on the placement of the temperature sensors in the structure of the bridge. The depth of placement was measured from the bottom of the working spaces of A - pier and B - arch, which were laid on insulation.

Place A – Pier		
Temp. sensors	Material	Depth of placement [m]
A	Loose material	1.37
B	LWAC	0.48
C	Cement mortar	0.10
D	Reinforced concrete slab	0.56
Place B – Arch		
F	Sandstone	0.99
G	LWAC	0.47
H	Reinforced concrete slab	0.48
I	Cement mortar	0.10
J	Below the pavement of the bridge deck	
L	Air temperature at the bridge deck level	
M	Lower soffit of Arch X (in the middle of the arch)	0.07

Tab. 2: Placing of temperature sensors in the structure of Charles Bridge

7.6. Measurement Results

The measurement results [6], [7], [12], [15], [20], [21] are summarized in a graphic form in the following figures 21-26.

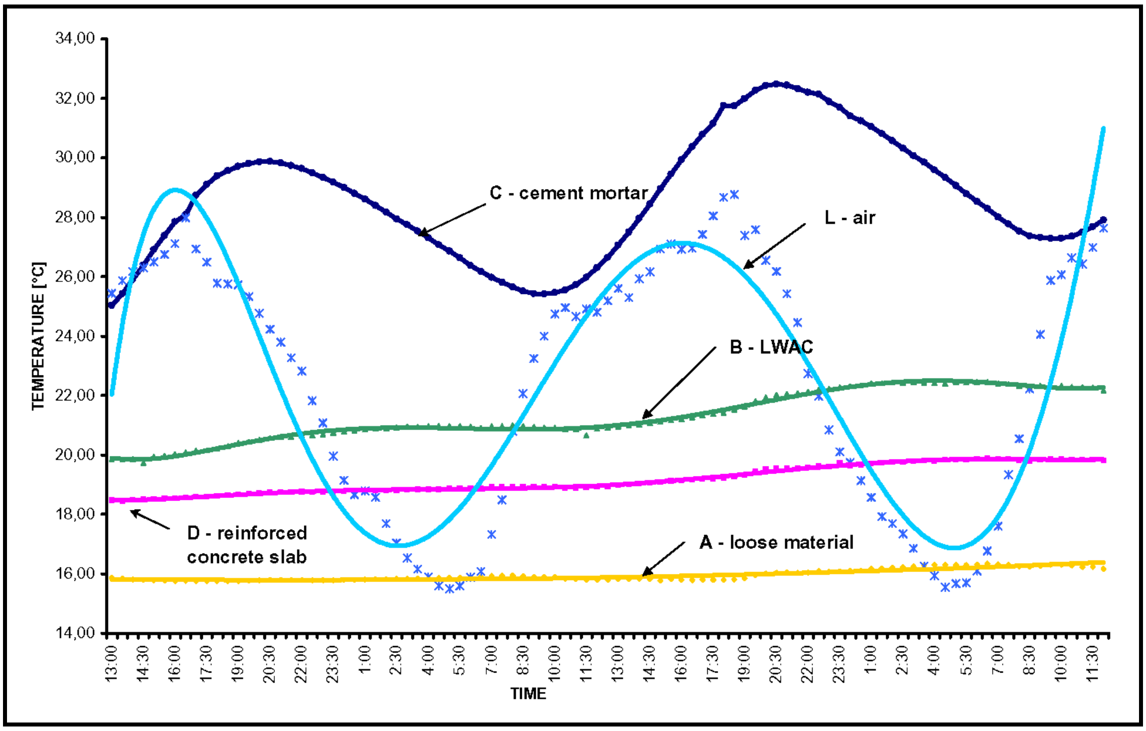


Fig.21: Charles Bridge – temperature field – pier, 5. – 7. 7. 1989

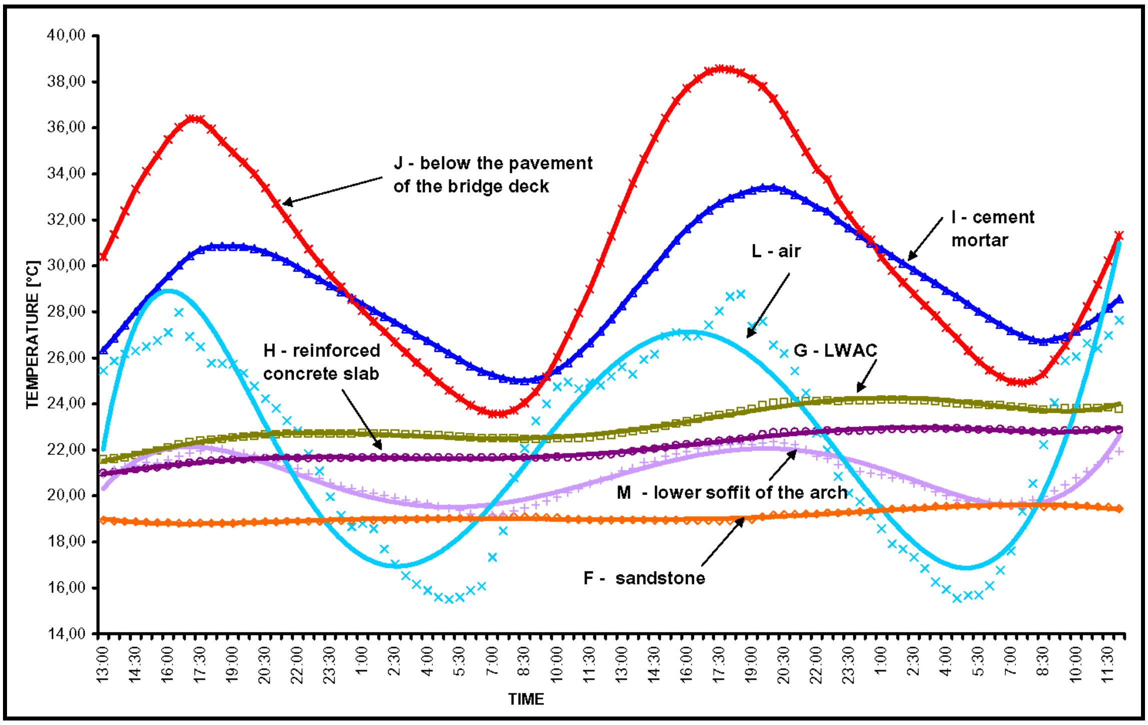


Fig.22: Charles Bridge – temperature field – arch, 5. – 7. 7. 1989

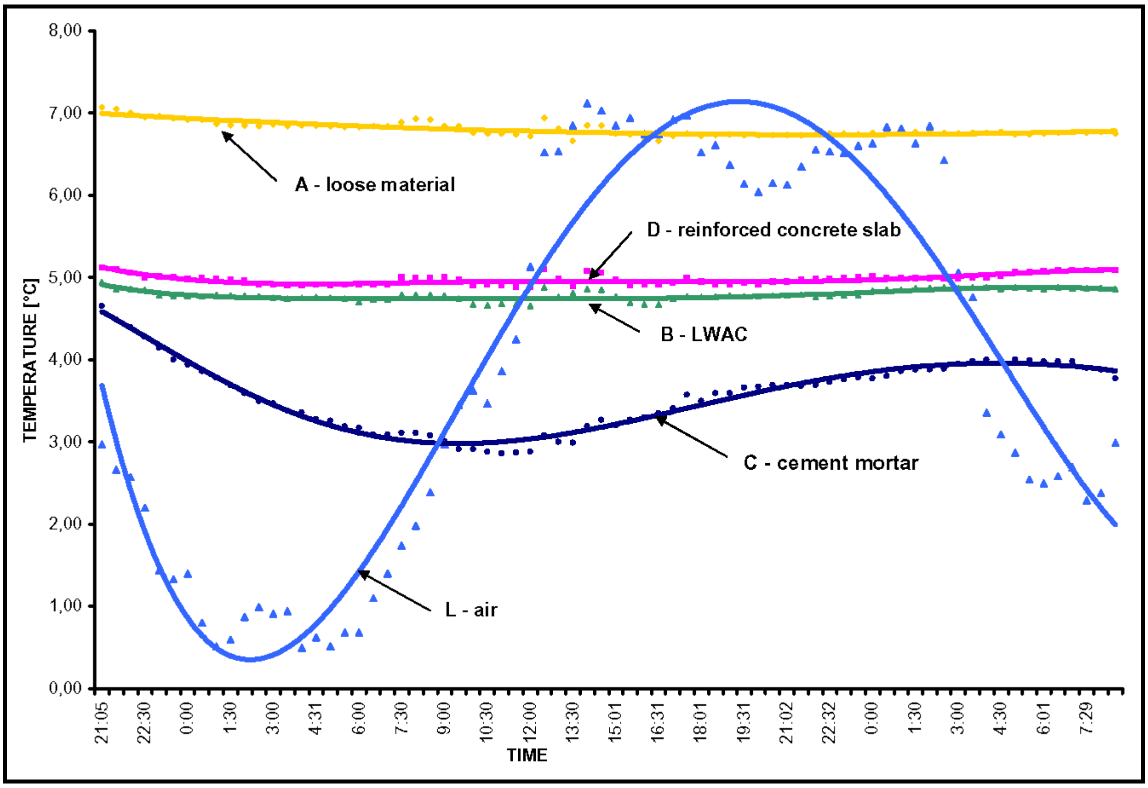


Fig.23: Charles Bridge – temperature field – pier, 9. – 11. 1. 1989

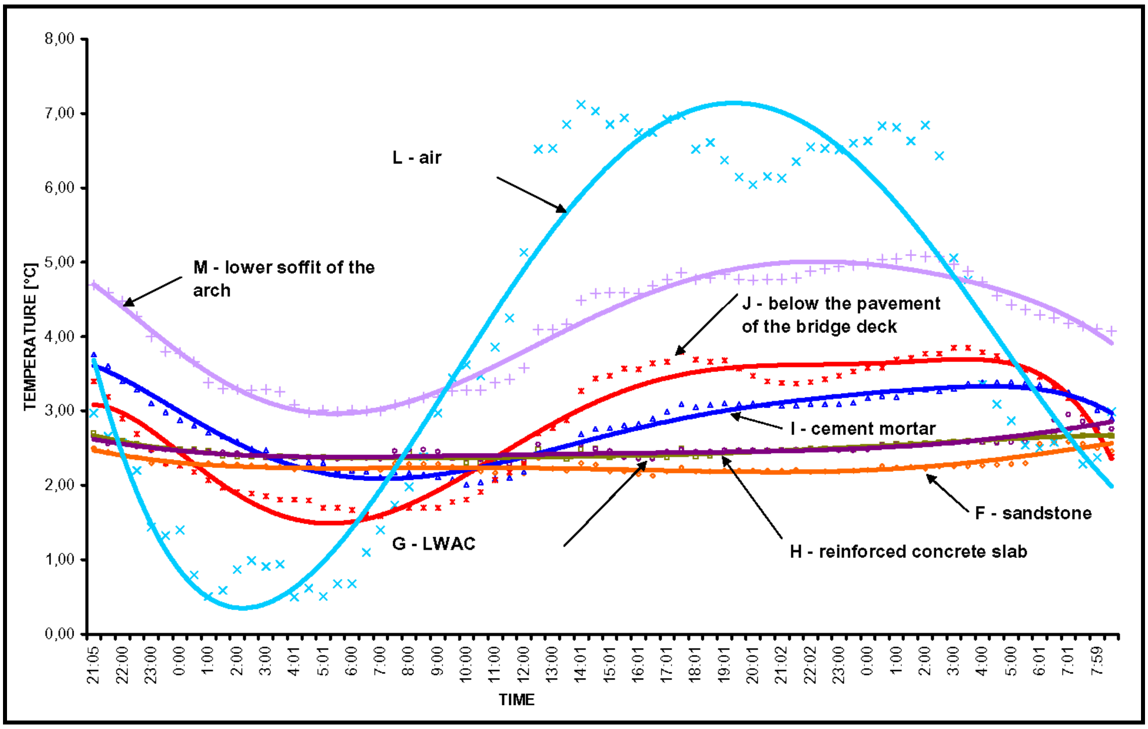


Fig.24: Charles Bridge – temperature field – arch, 9. – 11. 1. 1989

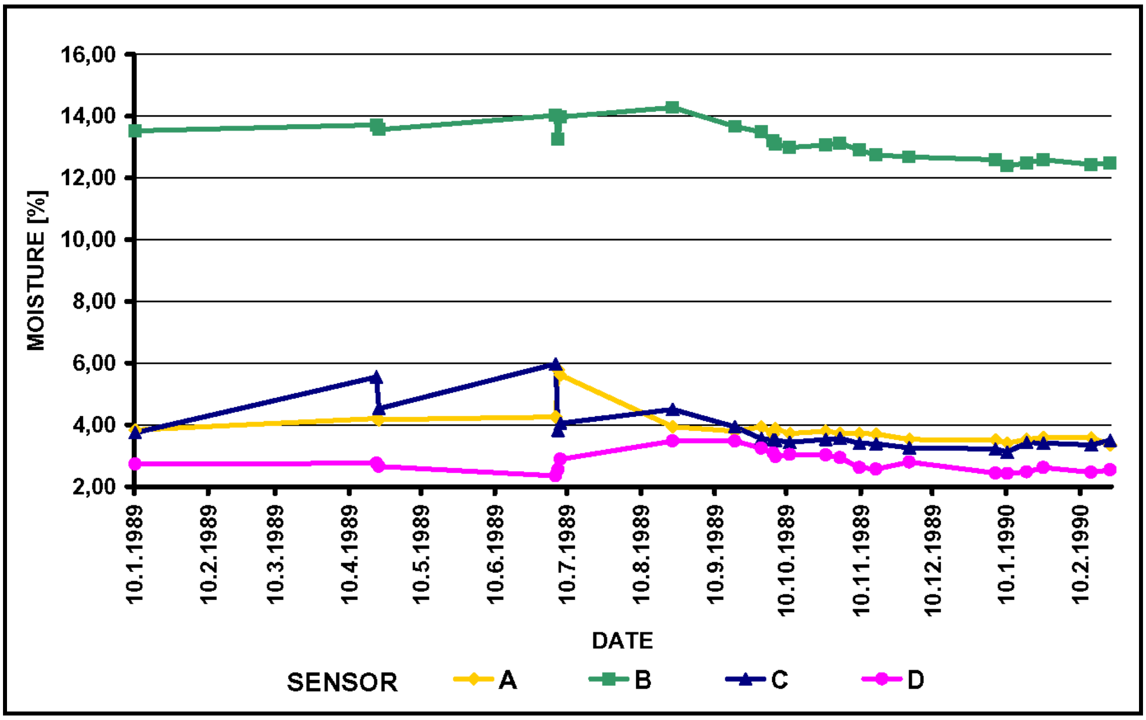


Fig.25: Charles Bridge – moisture field – pier, 10. 1. 1989 – 22. 2. 1990

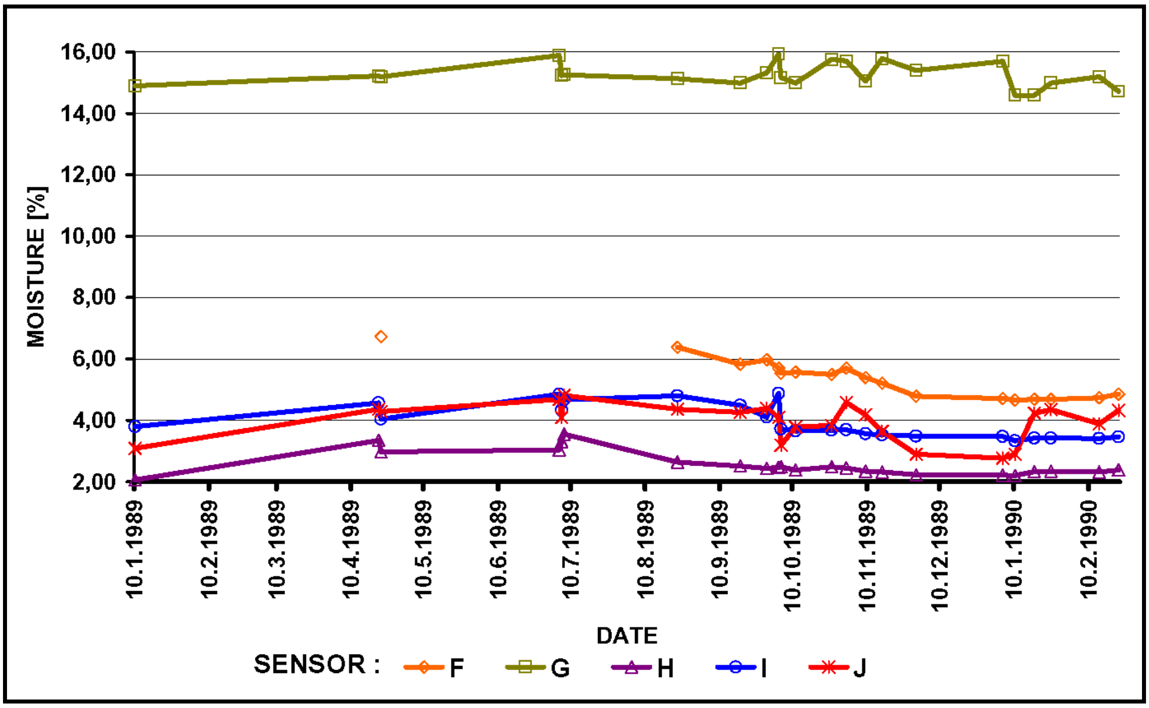


Fig.26: Charles Bridge – moisture field – arch, 10. 1. 1989 – 22. 2. 1990

7.7. Conclusion

The aims of the experimental project to measure temperature gradients inside the Charles Bridge structure through the depth of the bridge structure, including at the arch crown and in the pier in the selected Arch No 10, were met successfully.

The measurement results document different types of behaviour of the bridge structure in the area of the bridge arch and the pier resulting from extreme temperature changes during one year period.

The measurement of temperature gradients inside the Charles Bridge structure has remained the first extensive and detailed measurement ever performed in this historical structure. What makes it unique is not only the fact that it was conducted inside the bridge structure, but also its duration, as it extended over the period of three years. The author of the measurement considers the fact that the temperature sensors were placed inside the bridge structure as the principal benefit of the measurement. This arrangement facilitated measuring real changes of the temperature field inside the bridge structure in extreme temperature conditions in different seasons of the year. The invasion into the structure of the bridge was a key decision for the achievement of the goals set for this experimental project.

The results of the measurement of temperature gradients inside the Charles Bridge structure offer experimental data for mathematical calculations of the determination of the effect of the RC slab placed on the bridge on its entire structure [2], [3], [4].

The measurement results of temperature gradients in the structure are in contrast to previous unsuccessful temperature measurements, the methodology of which was based on the fact that the measurements aimed at determining temperature fields inside the bridge structure by mathematical simulation from surface measurement of temperatures and the surrounding air. This aim turned out to be unrealistic in case of Charles Bridge due to insufficient knowledge of material constants of individual building materials used in the bridge structure. The failure of the prior measurements was one of the reasons why this experimental measurement was demanded.

The experimental results of temperature fields measurement confirmed that the decision to measure temperature gradients inside the structure was justified. The methods and the way of placement of the temperature sensors in two places of the bridge arch, including in the pier and in the arch crown, as well as the construction of the working spaces in the bridge structure facilitated keeping the sensors and cables in the bridge structure. After moving away the measuring centre originally situated in the vicinity of the statue of Brunswick, climbers placed the cables in hardly accessible places of the bridge arch. As a result, the sensors have remained in their places and can be reactivated if needed. This arrangement offers an opportunity for renewal of this measuring in a version which is required by the current situation of preparations for Charles Bridge reconstruction.

The measurement of temperature and moisture gradients verifies measurement results achieved as part of other research and experimental projects [33], [34], [35] undertaken on Charles Bridge over the period of the last 20 years.

The measurements completed so far have proven that the temperature field in the bridge structure is affected not only by climatic effects of the environment, but also by the bridge structure itself. According to the measurements, the pier area has a clearly-cut core whose temperature stability, contrasting with the variable temperature field in the arch area, affects all physical processes in the bridge structure. These processes have a further impact on both partial and total deformations of the structure of the bridge.

8. PRAGUE LORETTO – MEASUREMENT OF THE MOISTURE CONTENT OF THE MATERIAL OF THE SCULPTURAL GROUP

8.1. Introduction

The requirement to measure the material moisture content of the sculptural group within the Prague Loretto complex was based on its condition in 1991. The sculptural group was in critical condition with typical symptoms of deep sandstone degradation in the form of chinks, cracks and surface spalling of the larger parts.

The objective causes of this condition were directly connected with the properties of the sandstone, which is relatively heterogeneous, with numerous hydrolytic transformations of ferrous minerals (limonite). Erosive failures had presumably also occurred in the sandstone in the more distant past, always provoked by water, and several attempts had already been made to conserve the sculptural group.

Fig.27: Prague Loretto

Previous conservation attempts on the sculptural group are the second, subjective cause of its contemporary dilapidated condition. The remains of conservation attempts can still be identified, namely in the form of fragments of various fillings and surface crusts, originally meant in good faith, but which today are the fundamental sources of secondary erosion and corrosion processes.

Based on the critical assessment of the situation of the sculptural group, an extensive programme was designed in agreement with the monastery management, with the aim of creating a descriptive model of the condition of the entire volume of the sculptural group with regard to the distribution of moisture maps inside the structure in relation to climatic conditions, namely, rainfall intensity and moisture content due to capillary elevation from the subsoil.

8.2. Measurement Results

The measurement results [13] involve the actual values of the mass moisture content in relation to the time of measurement and the positions of the measured points.

The experiment made it possible to collect the entire moisture data sets, the analysis and interpretation of which facilitate drawing wider conclusions on the moisture distribution inside the sculptural group, as well as the movement of the moisture zones inside the sculpture during 1992. It is also evident how the sculptural group reacted to heavy rainfall and how the water moved or was retained inside the chinks and caverns, or how it migrated through the porous sandstone system. A study of the moisture profiles enabled the water contributions due to capillary elevation and rainfall to be estimated.

Though some combinations of the measured points show considerable fluctuations of values depending on the actual moisture contents, it is possible to trace the basic moistening trends during the different seasons and also during the period of intensive summer drying up of the surface parts and their successive wetting after a heavy downpour.

In absolute values, the highest mass contents range above 10%, see Fig. 29, but with regard to the erosion and corrosion behaviour of the sandstone, the steady average moistening of roughly the lower half of the sculptural group ranging from 6 to 8% seems to be more dangerous, as this is approximately twice the value of the corresponding balanced moisture content of the respective sandstone. These values of moistening are probably the basic source of failures in the intermediate material stages of the structure.

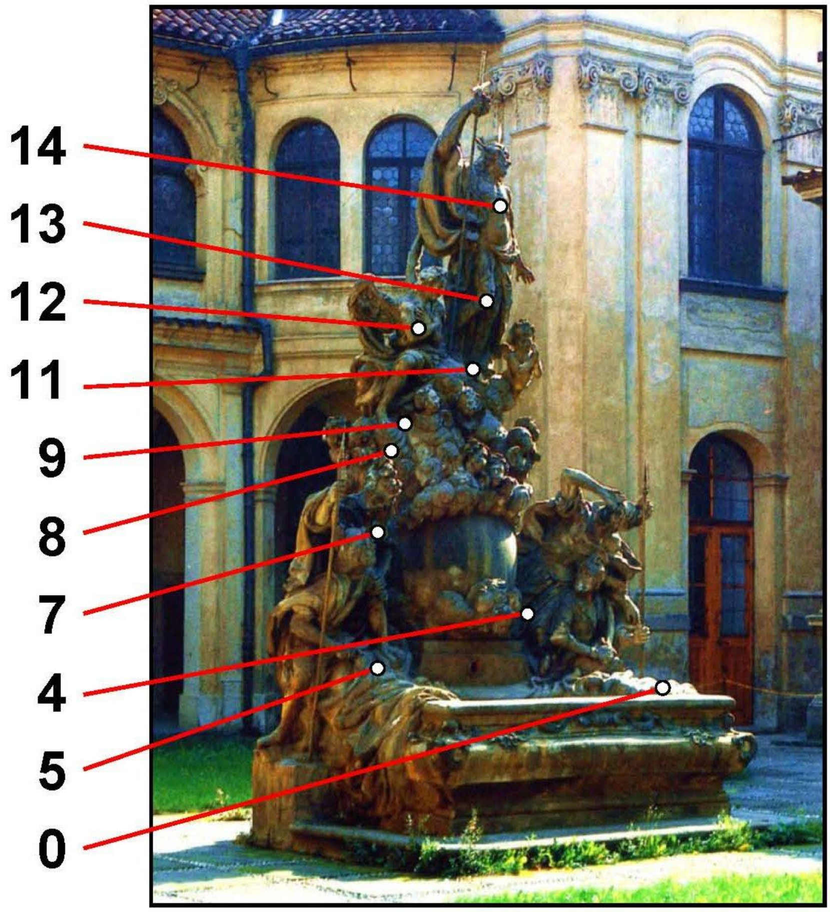


Fig.28: Fountain with the sculpture of The Resurrection of Our Lord
1739 – 1740
Jan Michael Bruderle and Richard Prachner

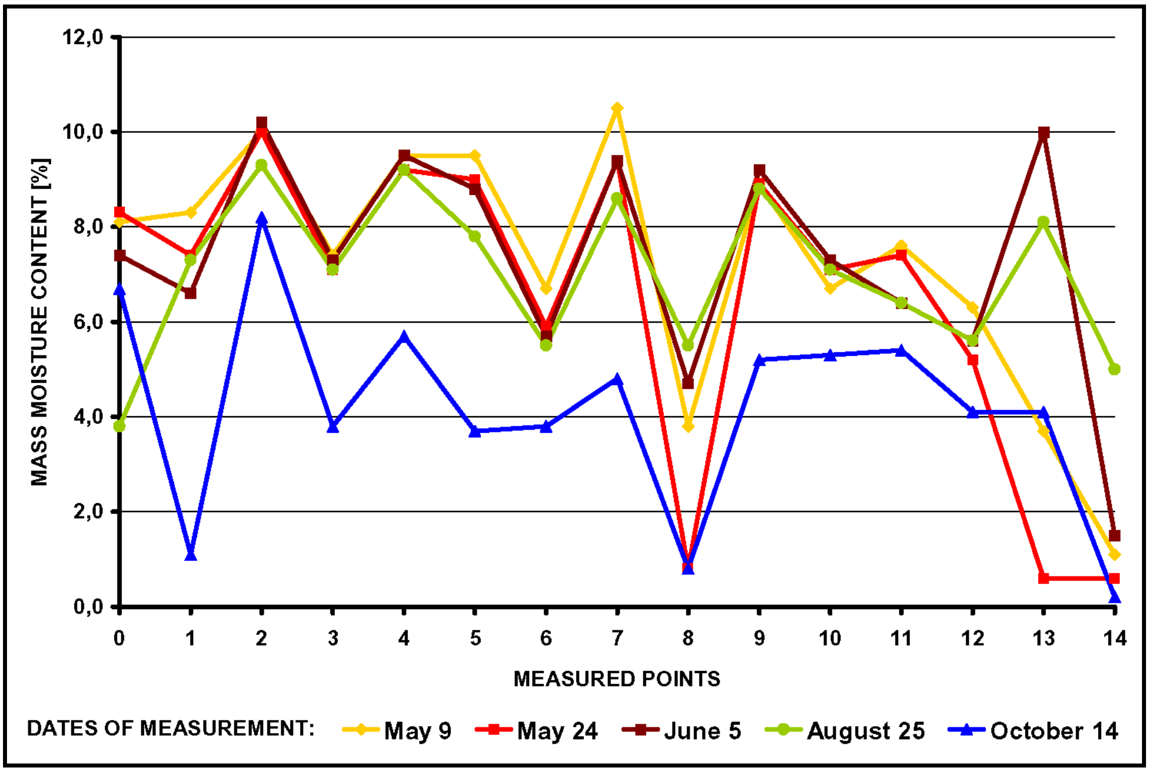


Fig.29: Moisture content of the sculpture material

8.3. Conclusion

The above-described measurements [13] of the mass moisture content values in the sculptural group Resurrection of Our Lord, located in the Paradise Court of the Prague Loretto show that the structure is exposed to excessive moistening practically throughout the yearly cycle. On average, the values of sandstone moistening are twice higher than would correspond to its average balanced contents.

The basic source of the current moistening of the lower parts of the sculptural group is capillary elevation of water from the subsoil. Contributions after rainfall cause high-level sandstone saturation, reaching up to values of around 12% of the mass moisture content, which must be regarded as critical moistening, namely in connection with the existence of watertight fillings and surface crusts. It should be emphasised that it is water in its various forms within the porous sandstone structure that is causing accelerating damage to the sculptural group.

To conclude, we recommend that long-term rehabilitation measures on the sculptural group require the installation of a damp-proofing barrier against moisture capillary elevation from the subsoil, and at the same time, the installation of roofing above the structure. Only complete elimination of excessive moisture sources can guarantee the success of any preservation or conservation interventions that will be needed on the sculptural group.

9. KŘEMEŠNÍK – MEASUREMENT OF VERTICAL GRADIENTS OF WIND VELOCITY

9.1. Brief Characteristic

It has become obvious that traditional sources of energy are limited, and the time has come for the energy source structure to become more varied and wider than in the past. Wind power ranks among new, untraditional sources of energy.

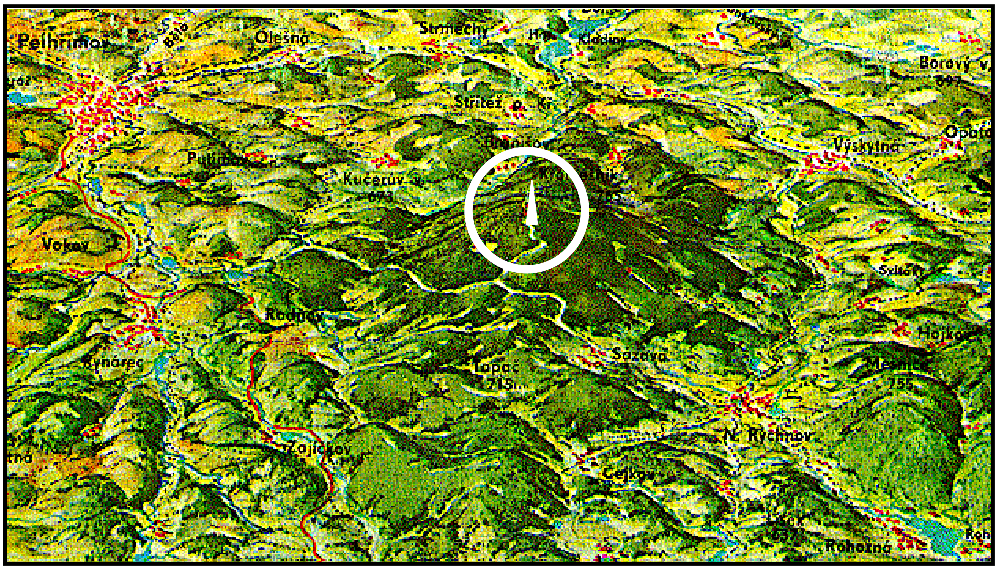


Fig.30: Křemešník – measurement of vertical gradients of wind velocity

Wind power generation has been very dynamic in countries of the European Union in recent years. To participate in this development actively is one of the tasks currently facing the Czech Republic, too. In order to achieve this goal, the Czech Republic needs to conduct a number of studies on potential exploitation of wind power and compare this potential with the conditions in the comparable countries of the European Union.

In 1993-96, the author of this presentation was the leading researcher of the EC Programme, Joule II-EUROWIN, JOU 2 - CT92 - O168:

- European Wind Turbine Database EUROWIN and Implemantation of an European Database EUSEFTA on Wind Turbine Failures.

The programme’s major goals included:

- the determination of vertical gradients of the wind potential up to the elevation of 50m above the ground with respect to the height of future wind power plants
- the measurement of the effect of vertical gradients of wind velocity on the high steel structure of the observatory tower of Křemešník.

9.2. Measurement Results

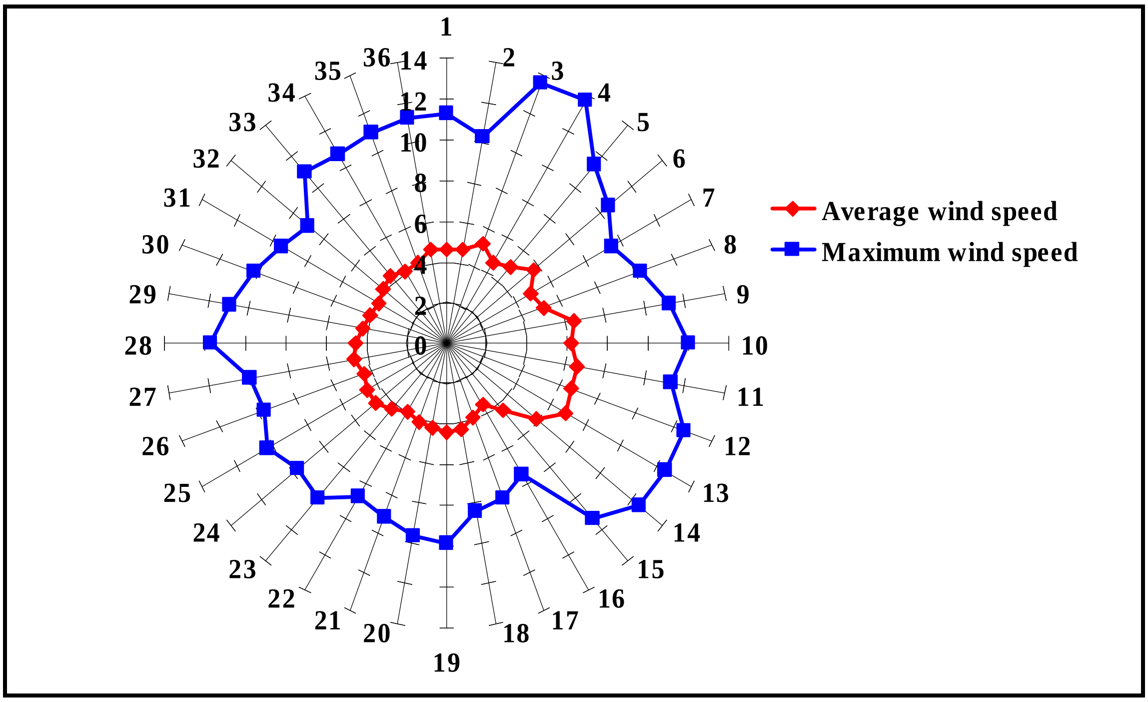


Fig.31: Average and maximum wind speed, Křemešník, July 1995

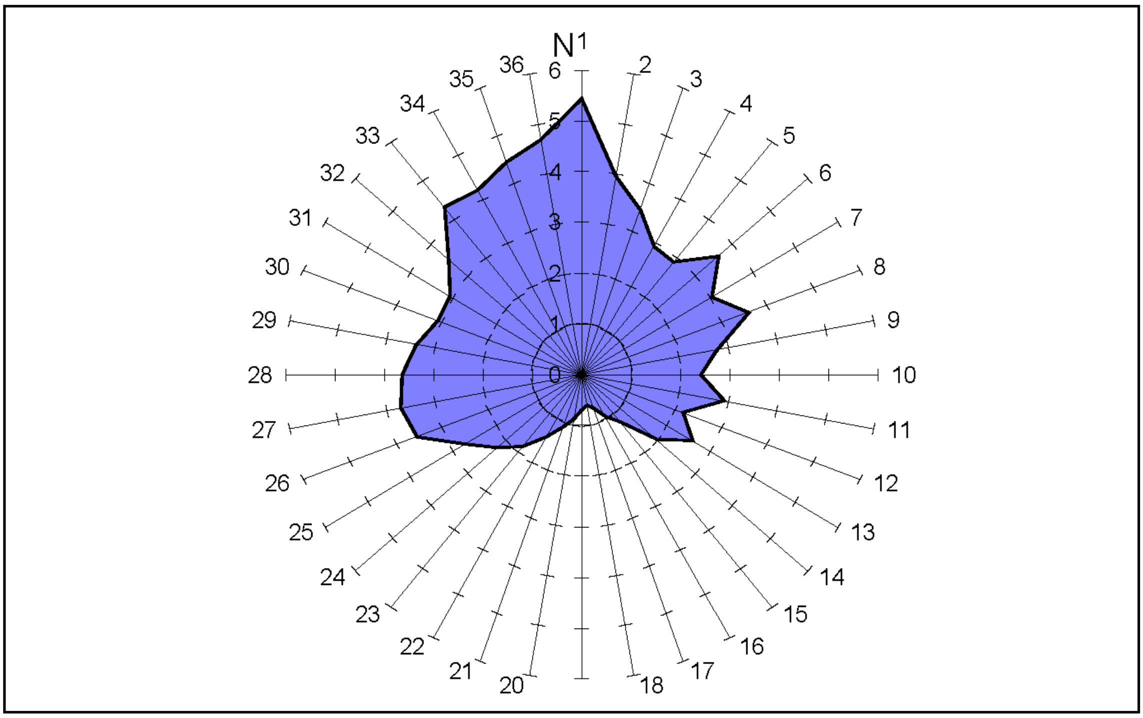


Fig.32: Frequency of wind directions, Křemešník, August 1995

9.3. Final Assessment

Within the EUROWIN project, unique measurements [22], [23], [24], [25], [26] were made. The importance of the programme is vital for the future installation of wind power plants in the Czech Republic. The measured energy curves of the wind potential can serve as a basis for the calculation of the future output of wind power plants, which appears to be a decisive fact for the construction of wind farms and their location viewing their maximum energy contribution. The absence of this measurement was a principal mistake in choosing the situation of some wind power plants already erected in the Czech Republic. As a result of their random location and unsuitable location, these power plants do not yield a corresponding output guaranteed by the producer. Consequently, these plants may cause unfavourable assessments of the potential exploitation of alternative sources of energy.

Fig.33: Křemešník, tower

Fig.34: Křemešník, tower

Fig.35: Křemešník, measuring sensor

10. APPLICATION IN PRACTICE AND RESPONSE OF THE PROFESSIONAL COMMUNITY

10.1. Benefits for the Practice

All the presented measurements were demanded by practical requirements, and they were always conducted on major facilities closely monitored by the public. The measurements were performed as an independent component of complex experiments. They were either made as part of dynamic structural tests of new bridge structures, or within a reconstruction, both completed and under preparation, of large bridge structures in the Czech Republic.

The measurements were, for the most part, extensive and took place in cooperation with major companies, such as PÚDIS Prague, Transport Works Prague, Doprastav Bratislava, SÚRPMO Prague, Transport Works Olomouc, Road and Railway Constructions Prague, and others. The measurements also involved the monitoring of further physical effects on bridge structures, e.g. solar radiation intensity and wind speed.

The author designed the measurement methods, developed the temperature and moisture sensors, put together the measuring equipment, and built the measuring centres for the recording, processing, and evaluating of experimental data in order to facilitate each programme of monitoring structures. These procedures took on simple forms initially, and gradually developed into the design of a modern measuring centre erected on Charles Bridge and the Nusle Bridge.

Measurements on all the bridge structures made it possible to generate a major database of experimental data, such as data on temperature and moisture fields, sun radiation, and wind speed. These data can be used for the assessment of the effect of climatic changes on bridge and building structures, and they can also be exploited in the future.

They will be useful in the case of Charles Bridge for example, the bridge deck and hydroinsulation system of which are going to be reconstructed. Designers and expert teams preparing the reconstruction currently use the measured data on moisture and temperature fields as source materials.

The database of experimental data has proven its significance not only for structural calculations of the loading of bridge structures due to changes of temperature and moisture fields, but also for the choice of materials to be applied in the reconstruction process. In the last general repair of Charles Bridge, civil engineers decided to apply lightweight aggregate concrete (LWAC) as thermal insulation, for example. Measurements of moisture fields of this material, though, proved high moisture content in the long-term. It did not change during the year substantially, and given the composition of individual layers of the hydroinsulation system, the use of this material turned out to be entirely inadmissible. Therefore, materials such as LWAC are now considered as totally inappropriate for future repairs of Charles Bridge.

The situation of the Nusle Bridge, which is permanently monitored, is similar. The measurements which the author conducted in 1980-82 (the pavement and the bridge deck), 1998-99 (the structural steel grid), and 2000-03 (the concrete structure) yielded experimental data which are currently exploited for simulation computations of the loading of the bridge structure as a result of temperature effects.

The results of long-term measurements of temperature fields on composite steel and concrete bridges (the Barikádníků Bridge in Prague and the railway bridges in Královské Poříčí) were utilized as experimental source material for the design of the due part of the ČSN 73 6203 - Bridge Load – standard.

The measurements performed on the Nusle Bridge in Prague yielded source data for some provisions of the ČSN 73 6242 standard on the Design and Construction of Roads on Road Bridges.

The measurements of the vertical gradient of wind power, completed within the European Community Programme, Joule II-EUROWIN, JOU 2-CT92-O168: European Wind Turbine Database EUROWIN and Implementation of a European Database EUSEFTA on Wind Turbine Failures, facilitated estimates of the wind potential in the region of Křemešník, as well as in the whole Czech Republic. Besides, they made it possible to determine the effect of the vertical gradient of the potential of wind speed on the high steel structure of the observatory tower of Křemešník.

The measurements of vertical gradients of wind speed up to the elevation of 50m, based on the methods determined as part of the EUROWIN project, have been the first measurements of this type ever conducted on the territory of the Czech Republic. They were completed in an international cooperation on the development of a new science field in the Czech Republic thanks to the collaboration of member countries of the European Union with other states.

10.2. International Response

Responses of the international professional community comprise above all 31 invited lectures, the most important of which are as follows:

- University of Cambridge (syllabus of the lecture is presented in an Appendix to this presentation)
- University of Dundee, University of Wales
- University of Nottingham
- Imperial College of Science Technology and Medicine London

The lectures delivered at European conferences, such as RILEM 1992, Weimar “Temperature Volume Changes of the Nusle Bridge in Prague“, European Community Wind Energy Conference 1993, Travemünde - Germany

“Wind Energy in the Czech Republic“, and the European Wind Energy Association Conference EWEC 94, Thessaloniki - Greece “Evolution of Wind Energy Potential in the Czech Republic“ are also notable.

Thanks to the international engineering community responses, the author became the main researcher of the European Commission Programme, Joule II-EUROWIN, Jou 2 - CT92-0168: European Wind Turbine Database EUROWIN and Implementation of a European Database EUSEFTA on Wind Turbine Failures in 1993-96.

The responses to the publication European Commission PECO 1993 published by the Office for Official Publications of the European Community, 1996, Brussels, Luxemburg are shown in an Appendix to this presentation.

The responses in the Czech Republic were, for the most part, called by the author’s measurements on major historical structures, e.g. Charles Bridge, and road communications, such as the Nusle Bridge, Barikádníků Bridge, motorway bridge in Velké Meziříčí, and the bridging at Masaryk’s Railway Station in Prague. In addition to the responses published by the professional community, they were also presented by television and the press.

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CURRICULUM VITAE

Doc. RNDr. Jaroslav Římal DrSc.

Education

MSc. (prom. ped.). 1961, Faculty of Sciences, Pedagogical University, Prague

Postgraduate course at Faculty of Mathematics and Physics, 1971-73, Charles University in Prague, solid state

RNDr., 1973, Applied Physics, Charles University in Prague

PhD. (CSc.), 1973, Czech Technical University in Prague

Associate Professor (Doc.), 1998, Physics, Czech Technical University in Prague

DrSc., 2001, Doctor of technical sciences in the field of the Theory and Construction of Engineering Structures

Work experience

since 1963 - Czech Technical University in Prague, Faculty of Civil Engineering

Major Pedagogical Outcomes

- lecturing for various branches of study at the Faculty of Civil Engineering, Czech Technical University in Prague for 40 years
- worked as a director of pedagogical laboratories of the Department of Physics for ten years
- created a video program Interference of Light and received the CTU Rector's Award in 1988
- introduced two new courses into the Master degree programme, including Geometrical Optics (now taught as Applied Optics) and Energy and the Environment
- designed four new courses into the Doctoral degree programme: 102OZE – Renewable Energy Sources and the Environment, 102PEH – Energy and Mass Transport in Building Structures, 102KVM – Effects of Climatic Changes on Bridge and Building Structures, and 102TOZ – Theory of Optical Imagery Applied to Geodesy
- led successful research teams, including both engineering and doctoral degree students, involved in the measurement of bridge and building structures in the Czech Republic
- engaged in doctoral students training; a member of the doctoral degree programme pedagogical board of the Structural and Transportation Engineering branch of study at the Faculty of Civil Engineering, Czech

Technical University in Prague; and a member of the doctoral degree programme pedagogical board of the Mathematical and Physical Engineering branch of study at the Faculty of Mechanical Engineering, Czech Technical University in Prague.

Research activities

- involved in the interdisciplinary area of application of physical measurements on building structures and materials
- conducted measurements on a number of major structures, including Charles Bridge in Prague, the Prague Loretto, the Nusle Bridge in Prague, the bridging at Masaryk's Railway Station in Prague, the motorway bridge in Velké Meziříčí, the railway bridge in Královské Poříčí, and the Barikádníků Bridge in Prague. The work has been exploited as a source material for decision making on putting structures (new bridges) into operation, or for reconstruction designs
- won international recognition as a specialist in wind power utilization; working in the field for over 25 years, being one of its founders in the Czech Republic; contributed to its development in the Czech Republic
- worked as the main researcher of the European Community Programme, Joule II-EUROWIN (1993 – 1996), based on an international cooperation with countries of the European Union in the development of a new scientific field in the Czech Republic
- cooperating with the European Organization for Nuclear Research in Geneva.

Publications

- wrote more than 110 scientific and research publications; created major publications as part of work on the European Community Programme; other prominent works were related to physical measurements on building structures

International responses

- won the European project funding; supervision of the project
- delivered a number of invited lectures (31) abroad; e.g. at the University of Cambridge, University of Dundee, University of Wales, University of Nottingham and the Imperial College of Science.

Most prominent projects

European Community Programme, Joule II-EUROWIN, JOU 2-CT92-O168: European Wind Turbine Database EUROWIN and Implementation of a European Database EUSEFTA on Wind Turbine Failures. 1993 – 1996, international cooperation in the development of a new scientific field in the

Czech Republic involving collaboration of member states of the European Union with other countries.

Project on the Measurement of Temperature Fields of the Structural Steel Grid of the Nusle Bridge in Prague within the reconstruction and later replacement of this grid in 1998-1999.

Project on the Measurement of Temperature Fields of the Bridge Deck of the Nusle Bridge in Prague within the reconstruction of the pavement in 1980-1981.

Project on the Measurement of Temperature and Moisture Fields of the Load-Bearing Concrete Deck and the Bridge Structure of Charles Bridge in Prague in 1987-1991. The project was carried out on the demand of practice – preparation of the reconstruction of Charles Bridge.

Project on the Measurement of Temperature Fields in Composite Steel and Concrete Bridges – the Railway Bridge in Královské Poříčí and Barikádníků Bridge in Prague. The project's outcomes were used as source materials by the designer of ČSN 73 6203.

Project on the Measurement of the Moisture Content of the Material of the Sculptural Group The Resurrection of Our Lord in Prague's Loretto. The measurement was made on the demand of the restorers of the fountain with the sculpture The Resurrection of Our Lord, 1739-1740, Jan Michal Brüderle and Richard Prachner.