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Experimentální vyšetřování stavebních konstrukcí a materiálů a jejich verifikace

Experimental Investigation of Building Structures and Materials and their Verification

Summary

Experimental investigation of building structures and materials presents very extensive problem, consist of implementation of many different fields of knowledge to the resulting process. Because the results are influenced by many uncertainities is needed make a comprehensive investigation for each basic procedure of experimental work. The main goal is how the data results can be influenced, how important these influences are and how is possible to eliminate or despatch them.

How was described above, the problem is very extensive, author is focused on the most common building material as concrete is. He provided a lot of experimetal works concerning material characteristics of concrete and determined the most important influences on resulting measured data. The most important of them are :

- size and shape of the specimen
- planarity and parallelism of the specimen
- type and speed of loading
- finishing of surface of the loading platens
- setup of sensors on the specimen and on the loading platen of loading frame
- driving of loading by increasing of deformation

Each of these parameters can have basic influence on resulting data. It is very important setup methodology of experimental investigation which can guarantee certain credibility and especially repeatability of measurements. That methodology was designed under the leadership of author and accredited and is used for all experimental investigation.

Experimental investigation of building structures is based on originality of solution which are applicated in situ. First, the prediction of behavior of the structure should be done including a simple structural analysis, selection of dominant parameters of the structure and assessment of type of measuring devices and software. Second, the actual measurements should be provided, consist of record block of measured data, their selection, special kind of data filtering and data calibration in relation to the reference point. Third, the right choosen results would be produced, including the measurement accuracy, the measurement uncertainty and verification, validation and variability of the results.

In presented work are discussed experimental measurements of building structures which has been provided in past few years. These measurements are interesting because of originality of concept of measurement devices. The first two experimental work are concrete slabs reinforced by GFRP reinforcement and prestressed T beams made from plain and smeared concrete.The other two practical examples are structure of Ruzyně airport radar and structure of roofing of Slavia football stadium.

In the end of the work is described problem of verification and validation of experimental data including variability of results of experimental measurements.

Souhrn

Experimentální vyšetřování stavebních konstrukcí a materiálů představuje velmi obšírnou problematiku, spočívající v implementaci mnoha různých oborů činnosti do výsledného procesu. Protože jsou výsledky zatíženy mnoha nejistotami, je třeba podrobit každou základní proceduru experimentu komplexnímu zkoumání. Jde o to zjistit, jakým způsobem mohou být výsledné hodnoty ovlivněny, jak významné tyto vlivy jsou a jak je možné je eliminovat nebo zcela odstranit.

Protože problematika experimentálního vyšetřování stavebních materiálů je velmi široká, zaměřil se autor na jeden ze základních stavebních materiálů – beton. K tomuto účelu byly provedeny mnohé experimenty, díky kterým byly zjištěny nejvýznamnější vlivy na výsledné měřené veličiny. Mezi tyto vlivy patří zejména :

- tvar a velikost zkušebních těles
- rovinnost a rovnoběžnost podstav zatěžovacích těles
- způsob a rychlost zatěžování
- úprava povrchu zatěžovacích desek stroje
- osazení snímačů na tělese a na zatěžovacích deskách stroje
- řízení zatěžování přírůstkem deformace

Každý z těchto parametrů může mít zásadní vliv na výsledné hodnoty, a proto je důležité sestavit metodický postup experimentálního vyšetřování, který by zajistil určitou věrohodnost a zejména opakovatelnost experimentů. Takový metodický postup byl pod vedením autora sestaven a akreditován a postupuje se podle něj při všech experimentálních zatěžovacích zkouškách.

Problematika experimentálního vyšetřování stavebních konstrukcí je založena na originálních postupech, které je třeba aplikovat in situ. K tomu je potřeba nejprve předem provést odhad chování konstrukce, včetně jednoduché statické či dynamické analýzy, výběr rozhodujících parametrů vyšetřované konstrukce a stanovení vhodných typů měřicích prostředků a software. Dále je nutné provést sestavení měřicí linky a vlastní měření, zahrnující všechny předvídatelné vlivy, zaznamenat měřená data, provést jejich selekci, speciálním způsobem tato data filtrovat a kalibrovat ve vztahu k referenčním bodům, Nakonec je potřeba správně vyhodnocená data vydat, včetně specifikace nejistoty měření, verifikace a validace výsledků a jejich variability.

V předkládané práci jsou popsána experimentální měření stavebních konstrukcí, které byly v posledních několika letech provedeny a jsou zajímavé zejména z hlediska originality sestavení měřicích prostředků. Jedná se o dva experimenty konstrukčních prvků – betonové desky, vyztužené GFRP tyčemi a betonové předepnuté T nosníky z prostého betonu a drátkobetonu. Dalšími z popisovaných experimentů jsou měření deformací konstrukce radaru na letišti v Ruzyni a měření deformací ocelové konstrukce zatřešení fotbalového stadionu Slavia.

V závěru práce je popisován způsob verifikace a validace výsledků měření včetně variability výsledků experimentálních měření.

Klíčová slova :
experimentální vyšetřování konstrukcí, experimentální vyšetřování materiálových parametrů, zkušební těleso, tenzometrický snímač, induktivní snímač, měřicí ústředna, zatížení, zatěžovací stroj, deformace, průhyb, pracovní diagram, tlakové změkčení, celková energie deformace

Kywords :
Experimental investigation of structures, experimental investigation of material parameters, testing specimen, tensometric strain gauge, inductive strain gauge, measuring device, loading, loading machine, deformation, deflection, stress-strain diagram, strain softening, energy of deformation

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I would like express many thanks to my colleagues from the Department of mechanics and the Experimental center and not last in line also to my family.

1. INTRODUCTION

During the past twenty years a great deal of research work has been carried out on an experimental investigation of building materials. The main aim of this research work is to increase knowledge of experimental investigation of material characteristics of building materials and building structures as well.

The most sought material property of building materials is probably strength despite the fact that in many cases other characteristics may be equally or even more important. This is understandable because the strength of the building materials is technical property of high importance. On the other hand, the strength is an elusive property. Even if all factors that are known to affect strength are constant, there still can be wide dispersion in the numerical values of the measured strength depending on how and how well the measurements are done.

2. EXPERIMENTAL INVESTIGATION OF BUILDING MATERIALS

2.1 Concrete strength

In most structural applications the concrete is in the center of interest. It is employed primarily to resist compressive stresses. In those cases, where other stresses are of primary importance, the compressive strength is still frequently used as a measure of the resistance because can be easily ascertained. For the same reason the compressive strength is generally used as a measure of the overall quality of concrete even when the strength may be relatively unimportant [1]. In adition to its practical significance the tensile strength of concrete plays a fundamental role in the fracture mechanism of hardened concrete. It is an accepted view that fracture in concrete occurs through cracking. This means that concrete fracture is essentially a tensile failure regardless of whether the fracture is caused by compression or other loading.

Therefore the mechanical properties of a hardened concrete are controlled to a great extent by the fact its tensile strength is about 10% of the compressive strength. In the practice, tensile and flexural strengths are most commonly utilized in beams and slabs. To avoid undue cracking in such structures the tensile strength is of special importance despite its low magnitude.

Perhaps the most important utilization of the shearing strength of concrete is in reinforced concrete beams to control thediagonal cracking of the beam under flexure. This is not a pure shear situation. The case of pure shear acting on a plane has only theoretical interest. The pure shear strength of the concrete is about 20% of the compressive strength [1].

The importance of the torsion strength of concrete is evident from the fact that the behavior of a reinforced concrete beam is pure torsion before cracking is similar to its corresponding plain concrete beam. The torsion strength of the concrete calculated by the plastic theory is usually somewhat highet than the tensile strength.

The impact strength of the concrete is important mainly in concrete piles and in certain military constructions. As a rough approximations the impact strength of a concrete is about 50% of its static compressive strength [2].

2.2 Deformations of concrete

It is natural that when a load is applied to a concrete body – it deforms. However concrete deformations can occur even without external loading. It can be caused by changes in temperature, moisture, internal chemical reactions and many other conditions. Since these deformations can be quiet large, they should be prevented or reduced to acceptable size.

Another way to classify concrete deformations as by whether they are elastic or inelastic, or plastic or permanent. A deformation is elastic when it appears and disappears upon application and removal of stress, otherwise it is called inelastic. Concrete produces both kinds of deformation – that is why concrete is called viscoelastic material [3]. The inelastic part is greater for the first loading then for subsequent loadings but continues to a certain extent for each application of load.

A third way to classify concrete deformations is by whether they are instantaneous or time dependent. A deformation is instantaneous if it appears and disappears at the same time when stress is applied or removed. Since the loading or unloading of concrete yielding the development or elimination of stresses takes time, instantaneous deformation and time dependent deformation are not entirely separable. It is known that a major portion of the elastic deformation of concrete is instantaneous

Different concretes vary widely in their response to load. The amount and character of the deformation depend on the properties of the concrete, its strength, the particular environment, the magnitude of the load, application of the load and the elapsed time after the load application when the observation is made [3].

2.3 Testing technique

The concrete as a most common material is usually tested in the laboratory conditions in the loading frames. The loading frame should be stiff enough to prevent distribution of loading to the frame columns. For compression tests on large specimens of concrete is usually used INOVA loading frame having the capacity of 2 500 kN. For smaller ones is better used MTS loading frame with capacity of 100 kN. Loading frames are provided with a hydraulic servomechanism, which has been used when loading a specimen in order to measure under the deformation control.A constant strai rate of $1 \,.\, 10^{-3}$ m/s is usually used.

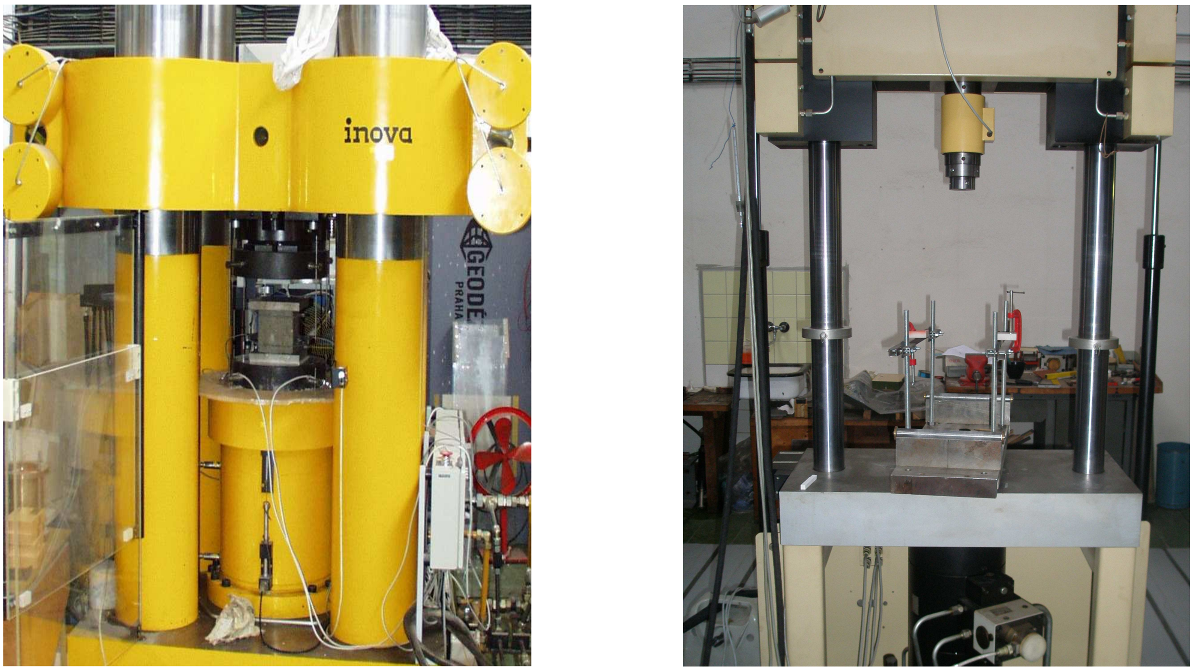

Figure 1 : Loading apparatus INOVA (on the left), MTS (on the right)

2.3.1 Measuring of strains

The axial strains are measured by means of tensometric starin gauges of different kind. The strain gauges are located in the loading frame on the two opposite sides of the specimen and symmetrically in the quarters of the round loading platens of loading apparatus. The separate readings of the two strain gauges located on the body of the specimen as well as of four strain gauges located on the loading platens are used for information on the uniformity of deformations of a specimen during the test.

Figure 2 : Location of strain gauges for experimental measurements

The measurements had to be corrected for the deformations of the loading platens and for extra deformations due to the setting of the loading platen against the specimen [4], [5].

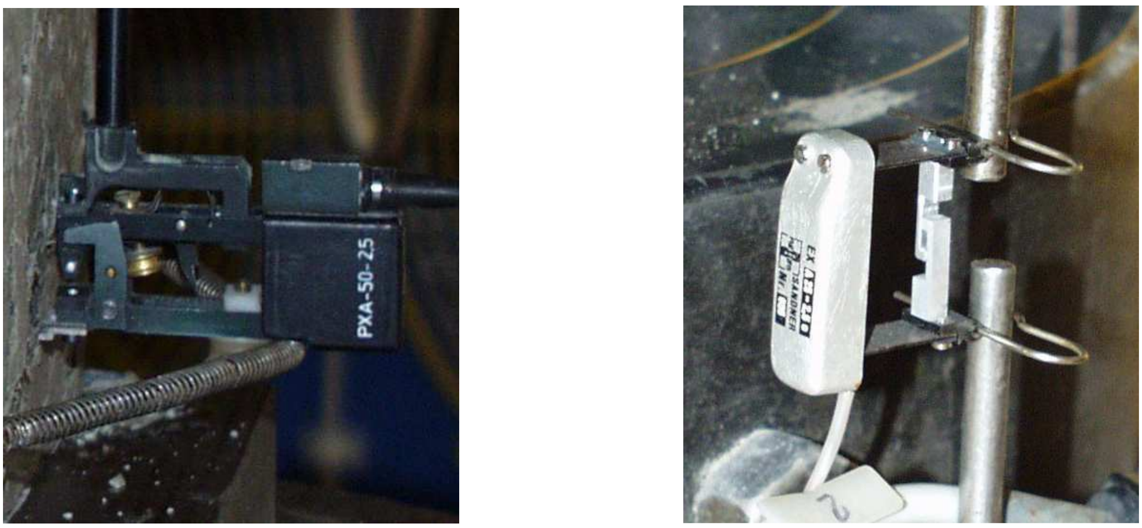

Figure 3 : Tensometric strain gauges

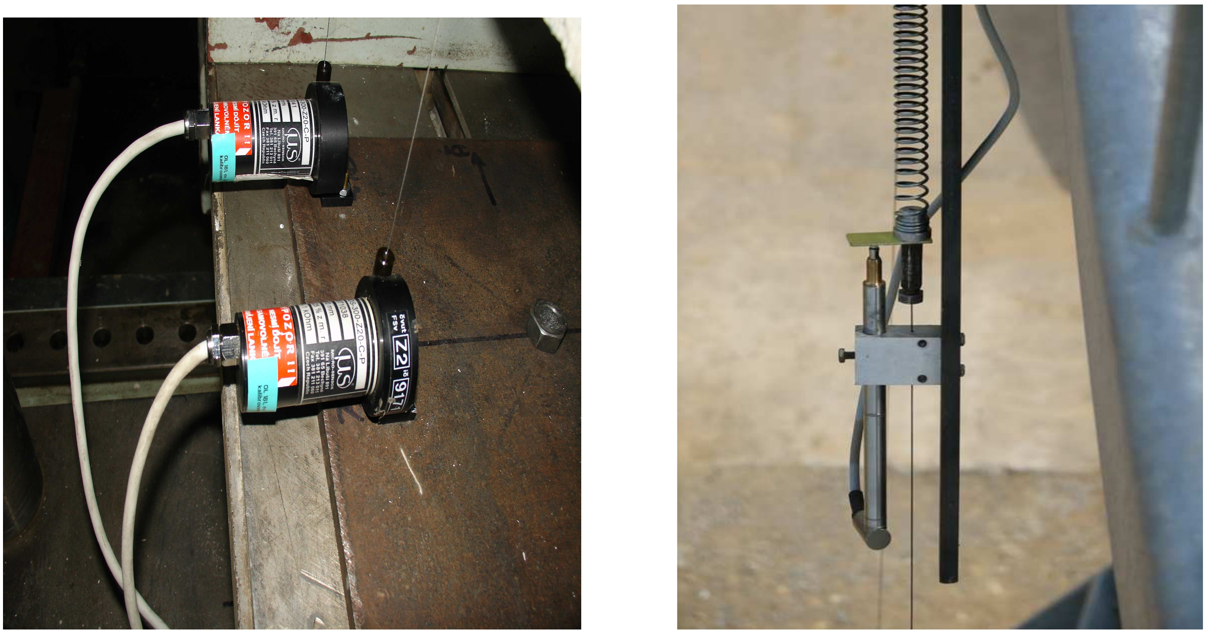

Figure 4 : Inductive sensors

This setting is due to nonflatness of the specimen surface, nonparallelism of loading platen surface and specimen surface and internal setting of the loading platens. The corrections have been made by the software by which the measured data have been evaluated. The correction methods have been extensively described in [6].

2.3.2 Preparation of the specimen

Special attention is paid to the flatness and parallelism of the loading surfaces. This is necessary for uniform loading. The top surface of the specimen is brught into contact with the platens of the testing apparatus. Because this surface is not obtained by casting against a machined plate, but finished by means of float, the top surface is rough and not truly plane. Under this circumstances stress concentrations are introduced and apparently the strength of the concrete is reduced. Convex boundary surfaces cause a greater reduction than concave ones as they generally lead to a higher stress concentrations. The lack of parallelism between concrete specimen and loading platen surface can be minimized by loosening the higes of the loading frame when placing the loading platen against the specimen [5].

3. EXPERIMENTAL INVESTIGATION OF BUILDING STRUCTURES

All of experimental work in situ consist of three consequential parts. First the prediction of behavior of the structure should be done including a simple structural analysis, selection of dominant parameters of the structure and assessment of type of measuring devices and software. Second the actual measurements should be provided, consist of record block of measured data, their selection, special kind of data filtering and data calibration in relation to the reference point. Third the right choosen results would be produced, including the measurement accuracy, the measurement uncertainty and verification and validation of the results.

In the past a large number of experimental investigations of building structures were done by the author as a principal investigator. In the next pages the only interesting examples will be described.

3.1 Loading test of the GFRP reinforced slab

Nowadays an inconsiderable attention is paid on new materials with better characteristics and longer lifetime as well. Regarding reinforced concrete, one of the most important thing that comes to mind is reinforcement itself. Corrosion, electric and thermal conductibility can decrease the material characteristics of the metallic reinforcement and therefore the lifetime of the structures as well. Nevertheless a non-metallic reinforcement offers an excellent behavior in terms of corrosion-proof ability, thermal and electric non-conductivity and other excellent characteristic. Moreover a very good strength of GFRP bar can approach the experiment to very interesting results.

Concrete GFRP reinforced slab is loaded in a four point bending test. Dimensions of concrete slab are to be seen on the Fig. 5.

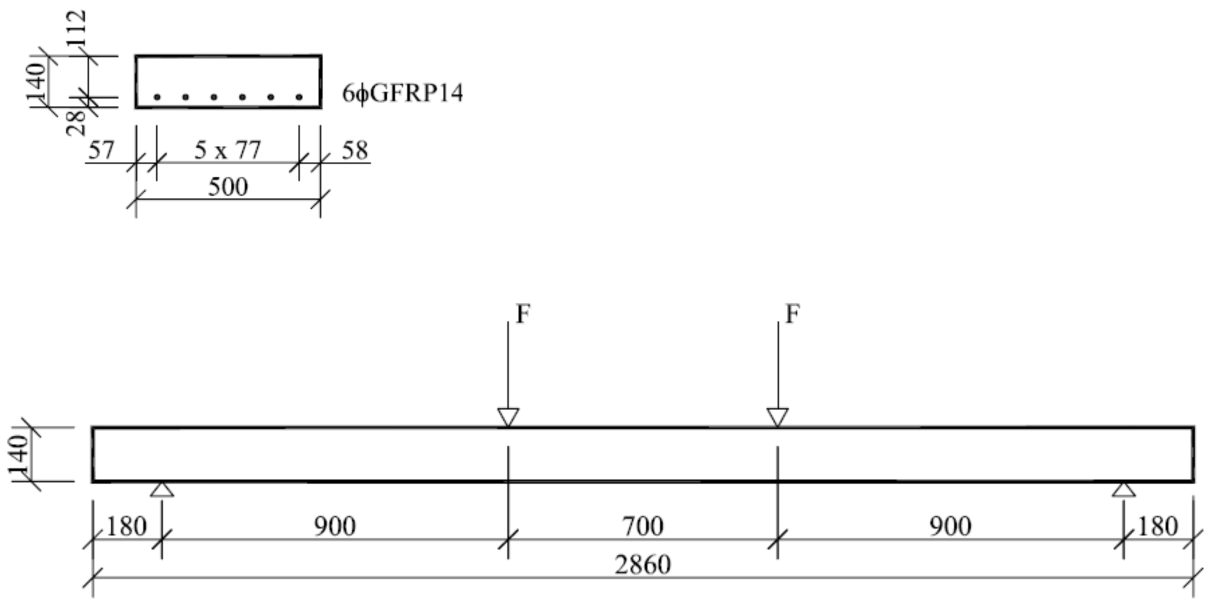

Figure 5 : Dimensions of the concrete slab

Concrete slab was reinforced with a six GFRP bars with two strings. Diameter of the GFRP bar is 14mm. All measuring data (deflection in the thirds and in the middle together with a force) was recorded in frequency of 2 Hz. Loading of the slab was carried out continuously along the time range. According to the standards, beam was two times loaded up to the 30% of the capability and unloaded. Afterwards slab was loaded up to the failure.

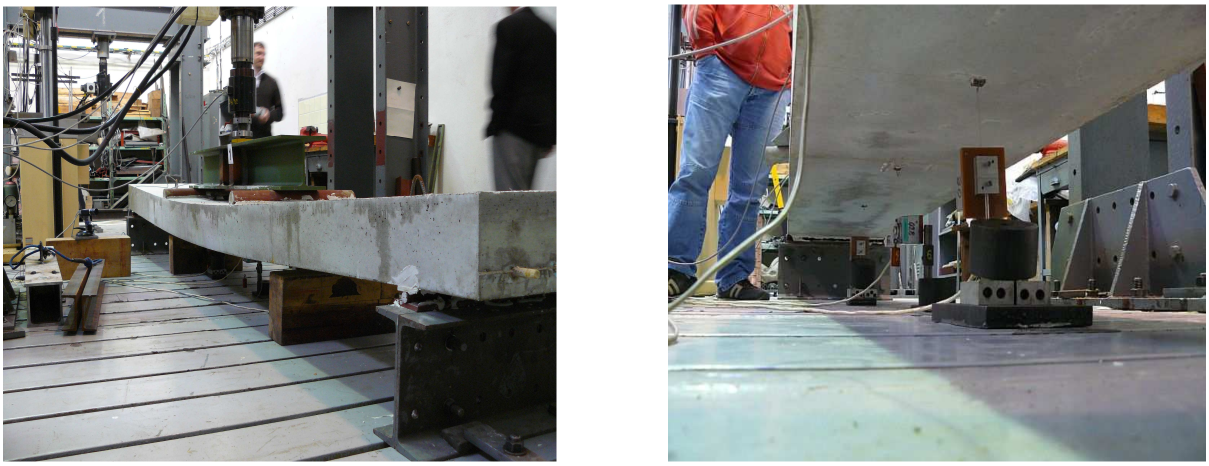

Figure 6 : Experimental setup in the laboratory

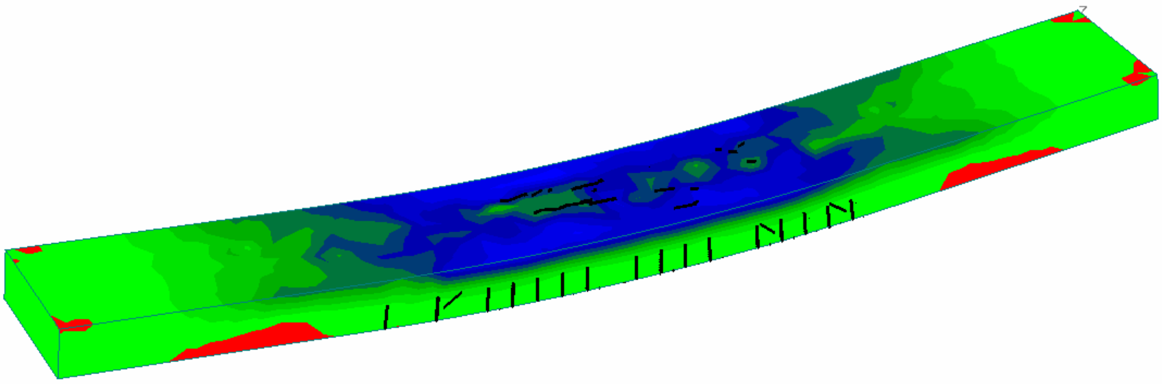

Figure 7 : Numerical analysis in ATENA software

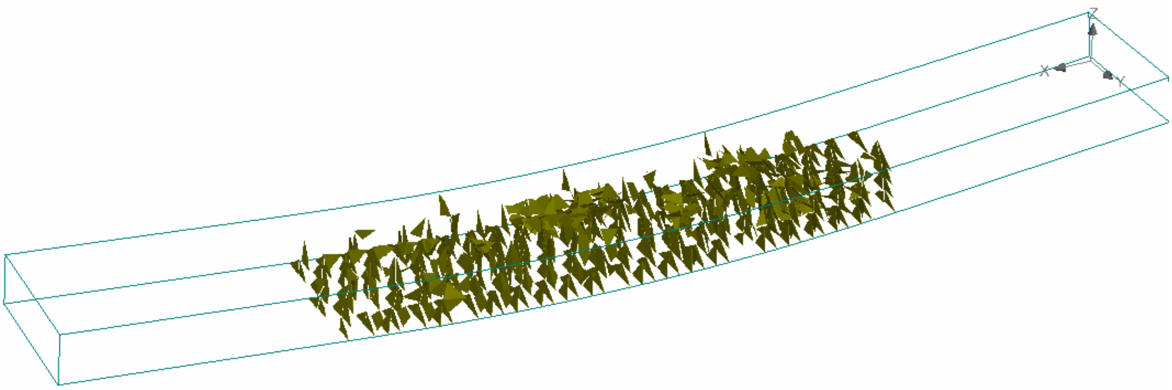

Figure 8 : Distribution of cracks in ATENA software

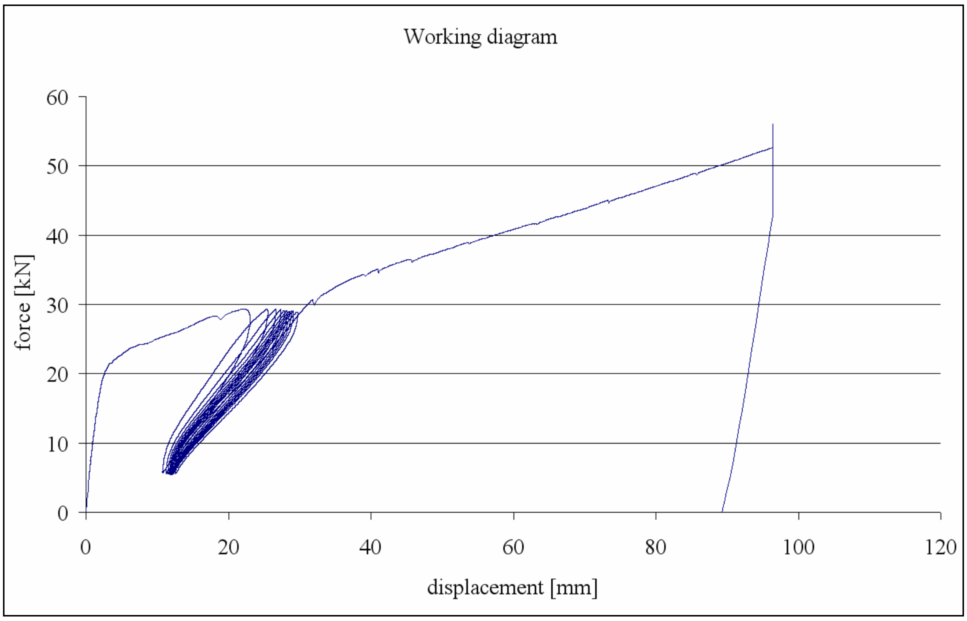

Figure 9 : Working diagram of the slab

A significant difference can be seen between the working diagrams of slabs reinforced with GFRP bars and slabs reinforced with a conventional steel reinforcement.

Behavior of the traditionally reinforced slab with a steel reinforcement can be divided into tree major parts. In uncracked stage slab behaves linearly up to the first cracks, when the tensile strength of the concrete is reached. When the cracks appeared, the stiffness of the slab goes down. In this point reinforcement starts to work. All tensile stresses are taken by the reinforcement itself. This is stage two. It last up to the point where the steel yields. Afterwards third stage begins, called cracked-inelastic. This stage is characteristics by a rapid increase of deformation with a minimum increase of the force. At the end of this stage slab fails.

Behavior of the slab reinforced with a Glass Fiber Reinforced Polymers can be divided into a two parts only. First stage goes hand in hand with slab with a steel reinforcement. When the tensile strength of the concrete is reached, stiffness of the slab decrease and GFRP reinforcement starts to work. This stage continues more or less linearly up to the point where the strength of the GFRP bar is reached. At this point GFRP breaks without any previous signs. No rapid increase of deformation or cracks can be seen. Therefore slabs itself fails as well. GFRP reinforcement doesn't have any plastic zone. Therefore it fails immediately at the point of the maximum strength. From this point of view, another safety factors must be taken into account.

Euro code doesn't include design procedure of concrete structures with GFRP bars. Therefore an American code ACI must be taken into account. American code establishes safety coefficient that reduce strength of the GFRP bar according to the type of the fibers and surrounding environment onto 70 – 100%. Another safety coefficient depends on the way of failure. If the bearing capacity of the element is limited by the tensile strength of the GFRP bar, safety factor reduces strength of the bar onto 50%. If the bearing capacity of the element is limited by the strength of the concrete, safety factor takes a higher value.

3.2 Loading test of the prestressed T beams

Main advantage of using smeared reinforcement is very high performance in the field of micro-cracks initialization. This point results in high strength of the smeared reinforced concrete. When using plain concrete micro-cracks are present wherever concrete is use in larger volumes. These micro-cracks results in a weakening that leads further on into a visible cracks eventually to the failure. Smeared reinforcement can prevent initialization of these critical cracks by increasing of cohesion of the young cement paste.

The goal of the experiment is investigation of behavior of two different types of prestressed T beams – made from smeared reinforcement and stirrup reinforced concrete in the age of 140 days. T beam is 3,5 m long, hight of the beam is 0,36 m. Upper flange has width of 0,3 m and thickness 0,05 m. Web of the T beam is 0,31 m hight and 0,08 m thick.Prestressed cable is placed nar the lower edge of the web. T beam is additionally prestressed on 1 400 MPa.

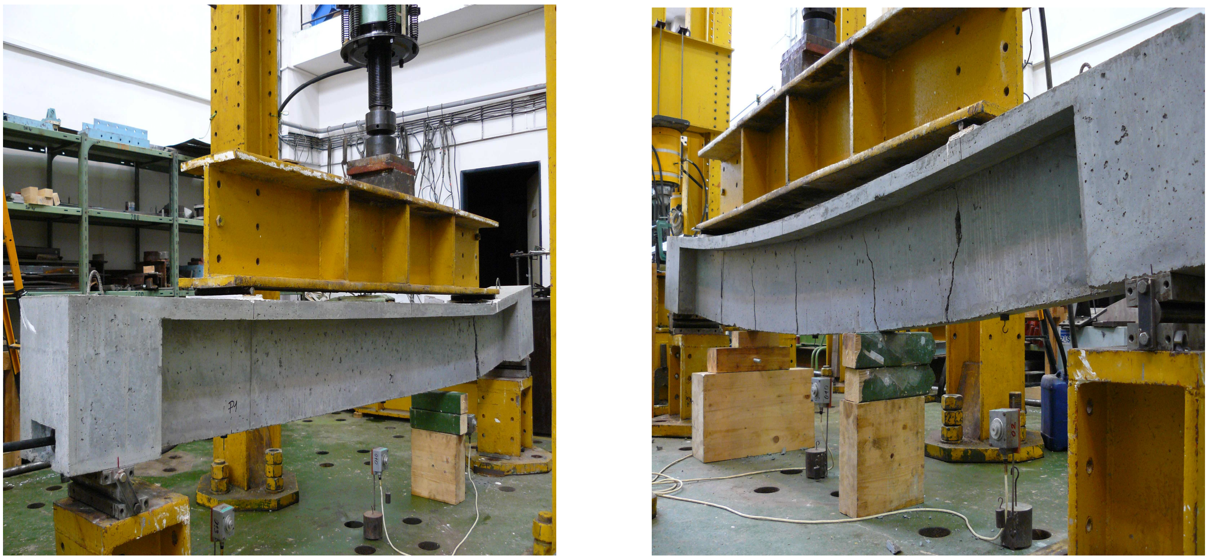

Figure 10 : Deformation of prestressed T beams (smeared concrete - left, plain – right)

T beam is loaded in a four point bending test in the way of shear failure. Forces are acting close to the supposts. Loading were carried out additionally in the steps of 30 kN, 15 kN and 9 kN according to the displacement and crack opening. Displacement was recorded by three sensors placed under the acting forces and in the middle of the T beam.

One crack only with a shear character right under the acting force was developed in the case of smeared reinforced concrete. This crack leaded further on to the failure of the entire element. On the other hand smaller cracks with bending character uniformly distibuted along lower edge of the beam were observed in the case of stirrups reinforced beam. Failure was reached right after the destruction of the prestressing cable than fire off the concrete element.

The type of the failure is very well seen on the Fig. 10. On left side of the figure is possible to see failure mechanism of T beam reinforced by the smeared reinforcement, on right side failure mechanism for plain concrete.

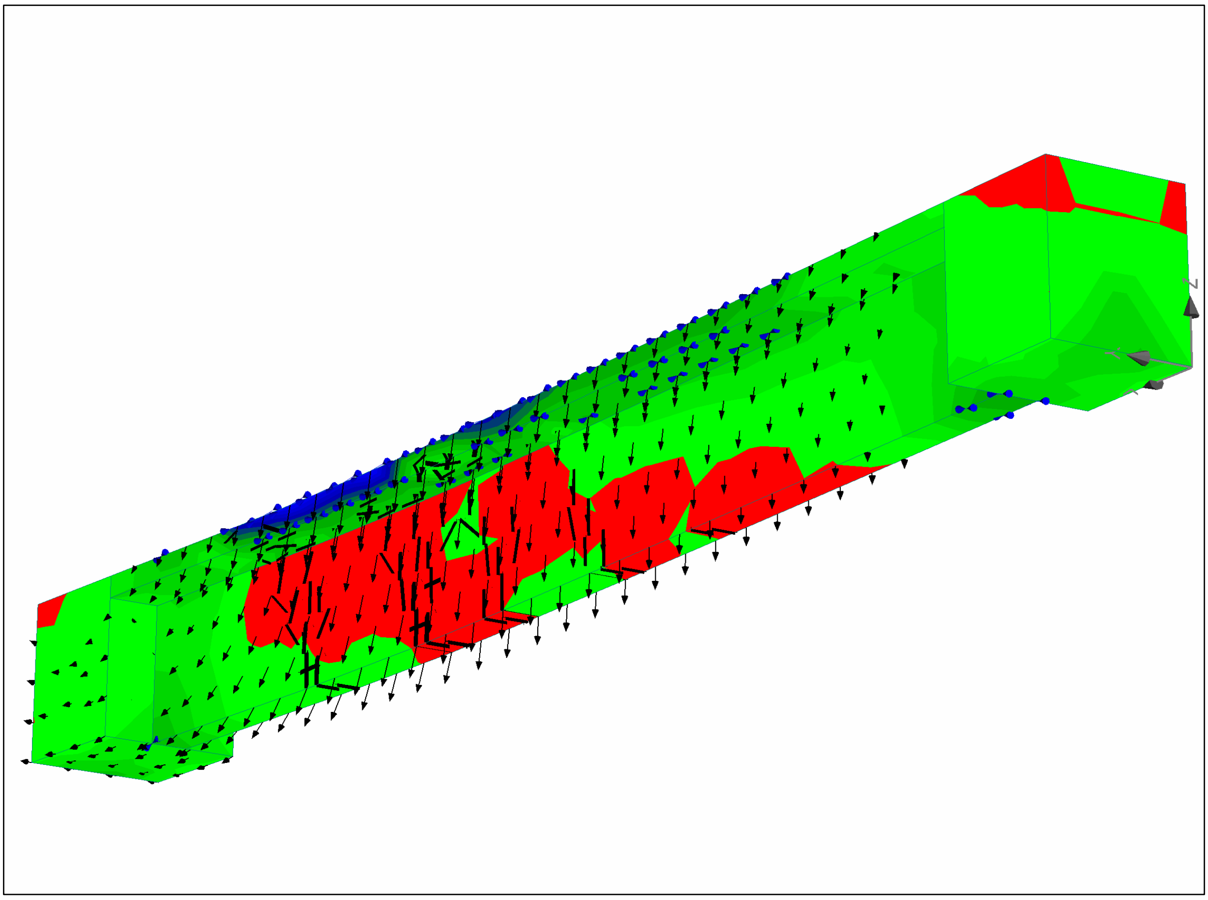

Figure 11 : Numerical model of the T beam in ATENA software

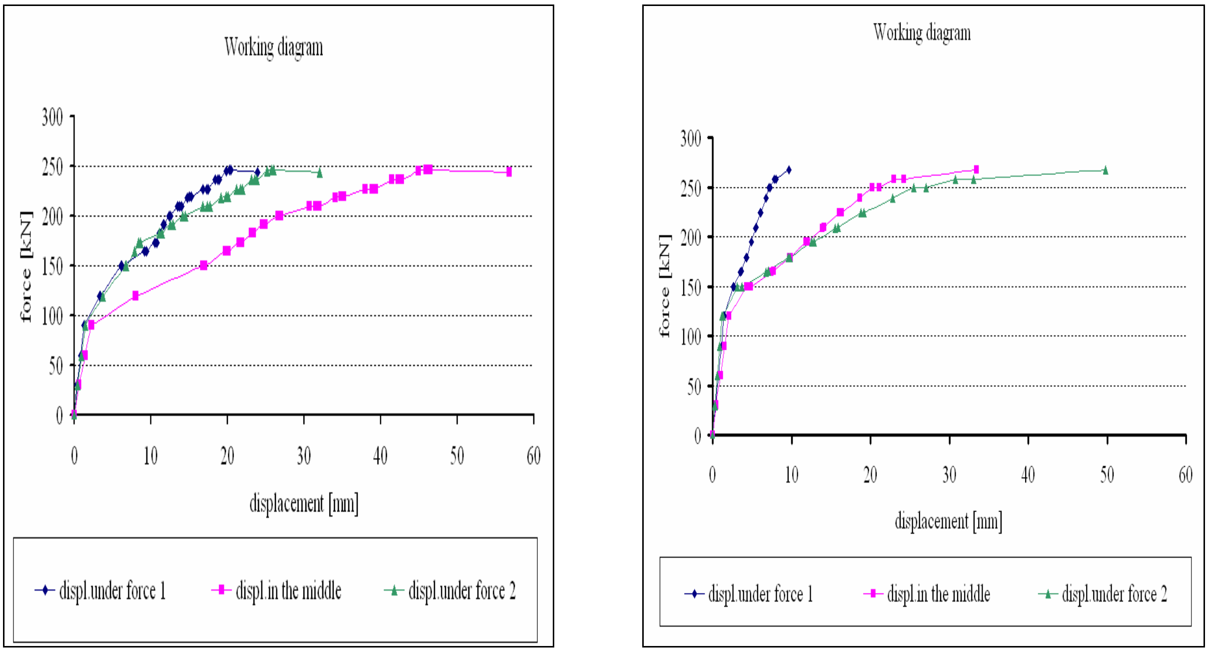

Figure 12 : Working diagram of the experiment (plain concrete and smeared concrete)

3.3 Loading test of the Ruzyně airport radar

Steel structure of the Ruzyně airport radar is located on the northeast part of the Ruzyně airport area. The structure is made from bars connected to the joints using bolts.

Figure 13 : Milunič design of steel structure of the radar

Hight of the structure is 25 m, requirements of radar device contractor were strictly indicated. Horizontal deformation of the floor have to be less than 3 mm, deformation in torsion of the floor must be less than 2 mm and vertical deformation of the edge of the floor not larger than 1,5 mm. As a most important loadings were choosen loadings of wind and temperature in combination.

For the experimental setup were used inductive strain gauges Hottinger Baldwin Messtechnik WA/20 located on the edge of the floor of the radar. Four of them for determination of vertical deformations in two perpendicular directions of the circle floor, two others for horizontal deformations and deformations in torsion. For complete assessment of the experimental investigation the sensors of temperature and sensors for measurements of wind speed were installed on different places of the structure.

Results of the experimental work were out of the range of the requirements of the contractor. The consulting engineers and the architect should strengthten the structure to additional diagonal beams. After that, all the deformations, measured and computed and shown on the picture of the display of data logger DEWETRON DEWE 5000 were in the range of the reguirements.

The maximum wind speed for measured deformation was 6,9 m/s.

Figure 14 : Mounting of radar structure by the HBM strain gauges

Figure 15 : Display of measured parameters of the structure

3.4 Loading test of the roofing of the Slavia football stadium

The roofing of the Slavia football stadium consist of steel truss beams supported on two supports with a cantilever of 18 m. These beams are connected by the steel trusses, on the top of the roof is metal plate, surface underneath is covered by the wood. The problem of the structure was the rigidity of the 150 x 100 m oval roof because of the dilatations in the thirds of the long side and in the half of the short side of the oval.

The computations showed very large changes during the day temperatures, so only experimental investigation of the main truss of the roofing could give the idea of behavior of the structure to the consulting engineers.

The measuring devices used for the experiment consist of measuring data logger DEWETRON DEWE 5000, inductive sensors Hottinger Baldwin Messtechnik WA/20 and optical laser sensors NCDT ILD1400-5 based on optical triangulation, connected together by long wire, tempereture sensor PT 100 and wind anemometer ANA 954.

Figure 16 : View on the Slavia stadium (design)

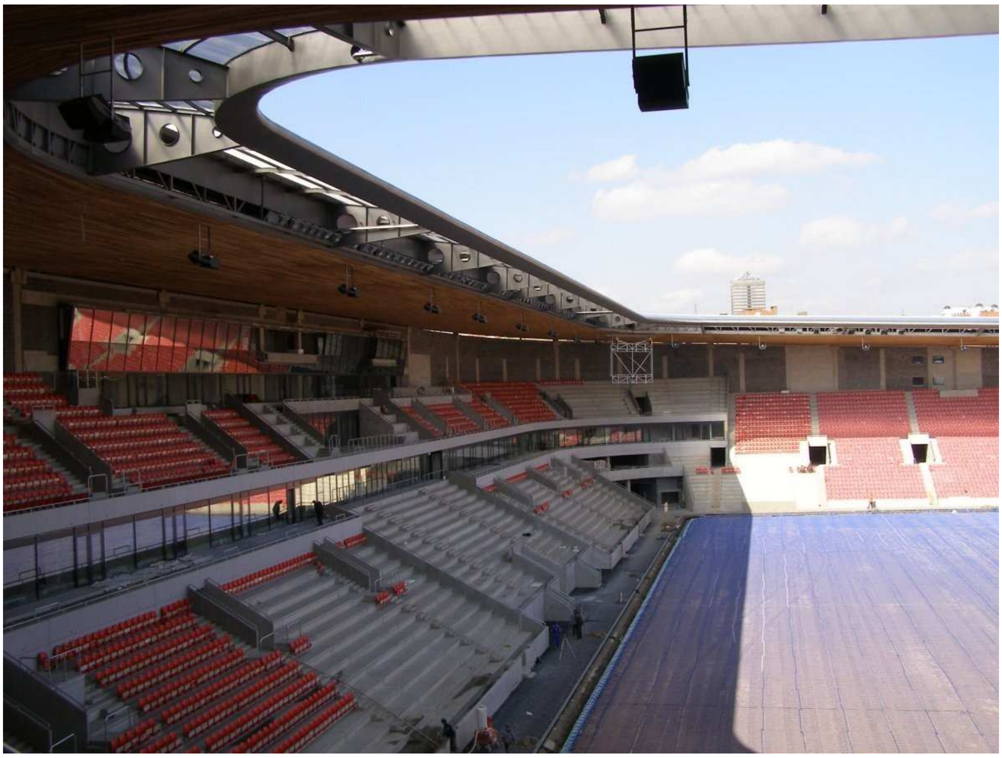

Figure 17 : View on the Slavia stadium (before opening)

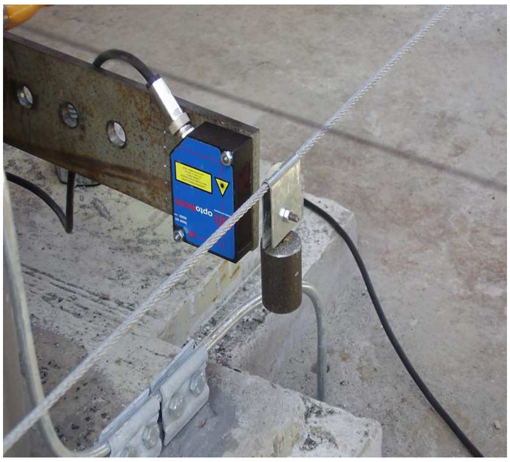

Figure 18 : Laser sensor NCDT ILD1400-5 on the left and strain gauge WA/20 on the right

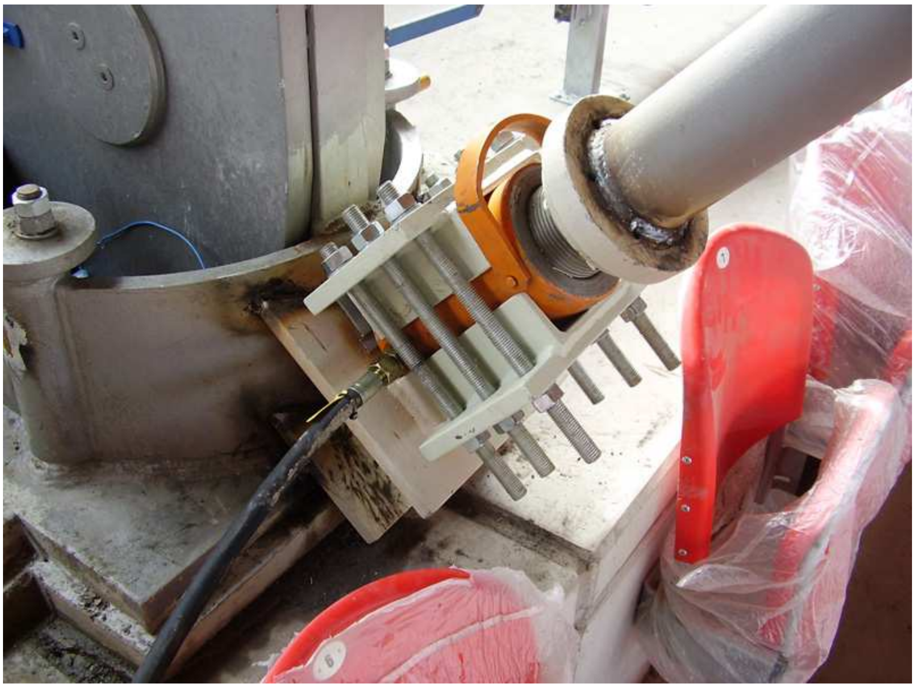

Figure 19 : Hydraulic loading member of the roof structure

The results showed on the Fig. 20 give the online values of the measured parameters of the structure, temperature and wind. Loading of the structure were provided using the hydraulic system in the level of 54, 111 and 164 kN as a force in diagonal support of the roof. Wind speed was in the range of 2,16 – 5,62 m/s and temperature in the interval from 12,6 to 13,3 °C.

As was mentioned above the structure of roof is symetric, loading of the structure nonsymetric because of the dilatations of the roof.

Maximum displacement of the roof was measured as 16.4 mm, residual displacement as 4.22 mm. Computations showed good agreement with the experimental data. Computational results are 31.2 mm and residual displacement about 7 mm.

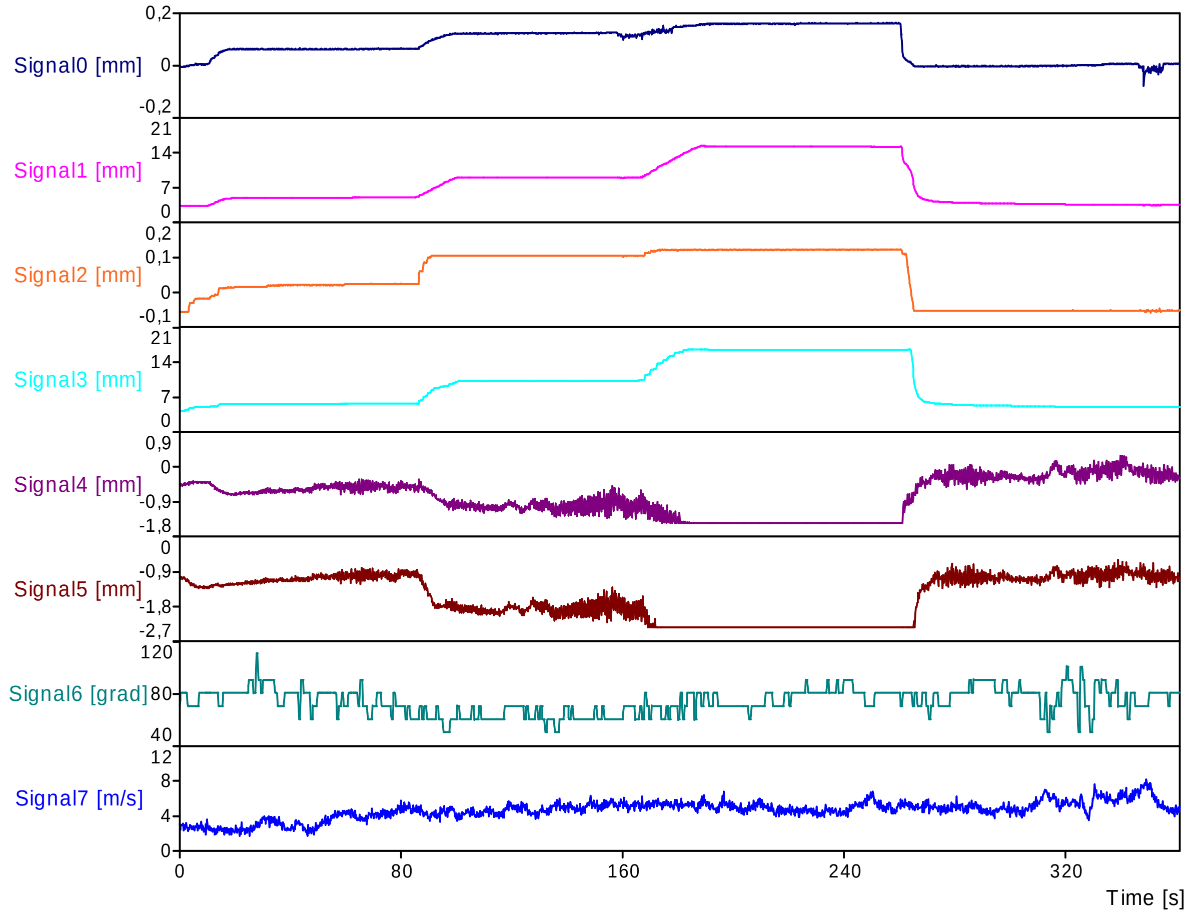

Figure 20 : Logging of the data from all sensors

4. VERIFICATION OF THE EXPERIMENTAL INVESTIGATION

Vast majority of engineering designs today is first treated by some computational method before being actually tested in practice. A prediction based on a mathematical model of the problem is the basis of the design. The reliability of the prediction depends on several factors: If the mathematical model represents reality correctly, then, if the input data for the model is correct, if the solution of the mathematical problem is correct and how the results are interpreted. All of these steps bring uncertainty to the final prediction.

Many times only small amount of information based on experiments is available as a base for mathematical model. The reliability of computed prediction is therefore questionable. In past, several engineering accidents proved this question is in place. The problematic of validation and verification deals with this question.

The terminology to this problematic brought by I. Babuška defines the process of *validation* as determining if the mathematical model describes sufficiently well the reality with respect to the decision which has to be made and *verification* as a process of determining whether the computational model and the implementation lead to prediction with sufficient accuracy, i.e. the difference between computed and exact solution is sufficiently small.

The basic purpose of computation is to provide quantitative data of interest upon which a decision is made. The mathematical model only transforms the available information into the prediction data of interest. The reliability of the prediction therefore depends on the quality of the available information. The mathematical model defines a general problem. When certain input data is brought in, the problem becomes specific. The mathematical problem is then solved by a numerical approach which creates a computational model. The relation between the reality and the mathematical model is the subject of validation while the relation between the solution of the mathematical and computational models is the subject of verification.

The uncertainty brought into the solution must be defined. Sources of uncertainty are in every step of described solution process. For example the input data obtained by experiments, experience, expert opinions always contain uncertainties. The specification of these uncertainties is usually not easy because not enough experimental data is available. The sensitivity of the mathematical model to uncertainties in different input values influences the decision which uncertainties in the input data have to be retained and which ones can be neglected.

The uncertainty can be aleatory or epistemic. The aleatory uncertainty is related to the physical uncertainty and cannot be decreased or avoided. The epistemic uncertainty can be in principle avoided by better experimental technology and better understanding.

The process of acquiring input data for general mathematic model making it specific is called calibration. The calibration have to be related to the point of prediction and can be performed both experimentally or computationally using simpler mathematical model. The calibration experiments are relatively cheap and are always different from the prediction problem which is often far too complex to be experimentally analyzed. The specific mathematic problem based on the calibration is the addressed in the validation phase.

The validation is related to the validation pyramid of experiments with increasing complexity. At the lowest level of the pyramid are simple calibration experiments which can be performed in large numbers due to their low cost. At higher levels the complexity of the experiments grows and the number of available experiments decreases due to increasing price. The highest level experiments are very complex and some times are called accreditation tests and serve as the basis for the demonstration of compliance with regulatory requirements.

The comparison between experimental and computational data during validation must be based on specific metric. This metric specifies a rejection criterion upon which the decision whether the model describes reality well enough or must be revised. The rejection criterion defines the tolerance of the validation. If the model at any level of the validation pyramid is rejected, the model has to be changed and to pass all the lower level tests. If the model is accepted, then higher level is performed.

The verification consists of mathematical and computational part. The mathematical part analyses the numerical method, convergence and a posteriori estimates an error. The computational part examines the correctness of the code and errors in the input data and other computer science aspects.

Verification is also important in calibration and validation. Verification of a computational model cannot be based on the comparison with the experimental data. Unfortunately, in practice the computational model is compared with the experiments so it is necessary to assume the computational model was verified, so that its error is negligible compared to the difference between computed and experimental data.

The calibrated model of specific problem is subjected to validation. The validation usually consists of several phases, taking from material coupon tests through small and large structural parts to complex experiments, which are often used also for accreditation. The validated model is then suitable for prediction. The confidence in the computed prediction is based on the computed distance between the calibration and validation data. For prediction only calibration data are used, while the validation data are used to characterize the confidence in the prediction. Typical calibration experiments include material coupon tests. Their aim can be very simple, e.g. only material strength or Young's modulus of elasticity value, or more complex, e.g. load-displacement diagram of the material.

Validation experiments can tests whole structural components, smaller or larger ones, e.g. solitary beams or structural components consisting of several parts like structural details. In largest scale is validation closely connected to accreditation demanded by regulatory requirements, e.g. loading tests of bridges.

5. VARIABILITY OF TEST RESULTS

All test results have to be interpretd in statistical terms. The mere fact, that values of some test results are larger than some other ones does not necessarily mean that the difference is significant and not a chance consequence of the natural variability of values from the same source. While all test results are variable those, derived from stress-strain diagram (for example) generally have a larger variability than in the case of standard compressive strength specimens.

5.1 Distribution of the strength

Suppose that was measured for instance the compressive strength of 100 specimens, all specimens were made from similar concrete. This concrete can be imagined to be a collection of units, all which could be tested. Such a collection is referred to as the *population,* and the portion of concrete in the actual test specimens is called the *sample.*It is the purposes of the tests on the sample to supply information on the properties of the parent population.

From the nature of the strength it would be expected that the recorded strengths will be different for different specimens, i. e. the results will show a scater. For illustration the distribution of test results and histogram of compressive strength values of many specimens made from similar concrete, fitted in the same conditions and tested at the same age. If the number of specimens is increased indefinitely and, at the same time, the size of the interval is decreased to a limiting value of zero, the histogram would become a continuous curve, a *distribution curve.* One such a type of distribution is known as *normal* or *Gaussian distribution.* The assumption of normal distribution is sufficiently close to reality to be useful tool in computations.

Equation to the normal curve, which depends only on the values of the mean μ and standard deviation σ reads

$$y = \frac{1}{\sigma\sqrt{2\pi}} \mathrm{e}^{\frac{-(x-\mu)^2}{2\sigma}} \tag{5.1}$$

This equation is representing normal distribution curve and is symmetrical about the mean value and extends to plus and minus infinity. The area under the curve, between certain values of strength (measured in terms of standard deviation) represents the proportion of specimens between the given limits of strength. The area under the curve between given ordinates, expressed as a fraction of the total area under the curve, measures the chance that the strength of an individual drawn at a random point x will lie between the given limits. Statistical tables give the values of proportional areas for different values of $(x - \mu)/\sigma$.

5.2 Standard deviation

It can be recognized, from the theory of probability, that the dispersion of strength about the mean is a fixed function of the standard deviation. This is defined as the root-mean-square deviation

$$\sigma = \left(\frac{\sum (x-\mu)^2}{n} \right)^{1/2} \tag{5.2}$$

wher x represents the values of the strength of all n specimens and μ is the arithmetic mean of these strengths, i. e. $\mu = \sum(x/n)$.

In practical using, one deals with a limited number of specimens and their mean x is an estimate of the true mean μ. Calculation of the deviations is provided by x not by μ, and therefore $(n - 1)$, instead of n, in the dominator of the expression (5.2) is used. Thus, the estimate of σ is

$$s = \left(\frac{\sum (x - \bar{x})^2}{n - 1} \right)^{1/2} \tag{5.3}$$

The reason for this correction of $n/(n - 1)$ is known as Bessel´s correction.

6. CONCLUSIONS

The experimental investigation of building materials is one of the most important part in the selection and the assessment of basic materials for structures. In these investigations are playing very serious role some aspects which the consulting engineer should take into account. In the testing of based structural material as concrete is were developed testing procedures and setups which give the complex imagination over its flexural behavior.

Testing technique, one of the fundamental process of laboratory work, was developed in the Experimental Center and Department of Mechanics of the Faculty of Civil Engineering and consist of special kind of capping of specimens, new arrangement of specimen sensors as well as loading machine sensors, using the steel rigid platens of the loading machine with special fashion and using new type of tensometric and inductive sensors.

For experimental investigation of building structures and their parts each experiment is an original one. First, the prediction of behavior of the structure should be done including a simple structural analysis, selection of dominant parameters of the structure and assessment of type of measuring devices and software. Second, the actual measurements should be provided, consist of record block of measured data, their selection, special kind of data filtering and data calibration in relation to the reference point. Third, the right choosen results would be produced, including the measurement accuracy, the measurement uncertainty and verification, validation and variability of the results.

On four examples were presented original procedures of setup of the measuring devices for experimental investigation of

- GFRP concrete slab
- prestressed concrete T beam
- steel structure of the radar
- steel structure of roofing of football stadium

These investigations are prestigious, investigator and his team did succeed in tenders engaged by the others reputable teams from over the Czech Republic.

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