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MONITORING OF CONSTRUCTION PROCESSES IN THE VARIABLE ENVIRONMENT

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Abstract. Interference problems of construction processes are especially disturbing due to their big scope of variability, uncertainty and complexity what significantly hinders planning and accomplishing the production processes on the building site. Monitoring of environment (which generates interference) and processes in progress enable to undertake activities aiming at introducing flexibility in managing of processes which may significantly increase the efficiency of systems ensuring quality in building. The described CONLI (CONcrete on-LIne) system is an effective device of monitoring which enables the transfer of information in real time to different decision-makers (e.g. site manager, supervision inspector, investor and the like) owing to wireless transmission and hybrid structure taking into account diverse scope of access depending on requirements of maintaining necessary data confidentiality.

Keywords: monitoring, construction management, construction process, flexibility, concreting.

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1. Introduction

In the beginning phase of concrete maturing, the main problem, especially in massive constructions, is the influence of autogenous heating of concrete on the increase of internal stresses and formation of cracks. Determination of rules and algorithms which could enable to simulate and plan the proper course of concrete maturing is essential to develop an effective system to ensure quality during concreting. Despite many years devoted to research and experiments this subject is still relevant today. On account of different dimensions of concrete elements as well as time and conditions of their preparation, and above all the

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applied types of cement and additives, it is difficult to develop algorithm ensuring sufficient conformity of planned (designed) process of maturing of concrete with reality. Constant development in the field of data collection systems (detectors, wireless transmission and the like) and decision-making support systems (advisory systems with hybrid structure as the following stage after expert systems) creates potential chances of significant advancement in managing building processes.

Environment variability is a basic problem during building processes. On account of this, it is highly beneficial to create a possibility of monitoring the environment and processes in progress and make decisions sequentially based on the results obtained in real time (Paslawski 1998, 2004b). The key role in this approach plays monitoring of building structures both in construction and operation phases. Analyzing the application of different techniques of management support in building within the space of total life cycle of a structure, special attention should be paid to the role of monitoring as not only an online source of data during construction and operation but also the possibility of using data collected by monitoring in other stages (e.g. designing). From the contractor's viewpoint it is particularly important to achieve the determined parameters of construction at the moment of acceptance; however, from the viewpoint of total life cycle of product, obviously it is crucial to ensure proper functioning of construction in the phase of operation. It is essential to state that a proper course of construction processes is necessary to ensure proper course of operation. Many serious problems during the operation of building structures result from the lack of monitoring the construction processes (Paslawski 2003a, 2004a, 2005a, 2005b, 2006, 2007). Taking into account the long product life cycle in construction industry and various possible (and difficult to predict) scenarios of operation (resulting e.g. from modernization of production processes, means of transport etc.), the possibility of monitoring and learning from examples acquires particular significance. Owing to vast amount of data, the use of decision support systems in the form of advisory systems seems to be indispensable. Moreover, the attention should be paid to potential wide possibilities of applying IT in building also with the use of monitoring (Kaplinski 2008).

The essential factor in the course of concrete maturing process is a change and scope of temperature both inside and outside as well as temperature gradients in proper sections. Therefore, it may be concluded that in order to create concreting process management system it is necessary to build a database to collect essential features, factors and temperature distribution in the beginning phase of maturing for various concrete elements. In order to improve information monitoring, gathering, transfer and exchange, it seems necessary to use popular and easily accessible communication devices such as Internet, mobile communications – wireless data transmission via GSM and GPRS which considerably facilitates data gathering and decision-making and above all managing construction processes on operation level in real time.

The subject of this article is to present the idea of CONLI system for monitoring building processes during construction on the example of monitoring concreting processes in the beginning phase of maturing. The aim of this article is to present the system monitoring building processes, the main advantage of which is the opportunity to exchange data in real time over a distance from dispersed construction sites. The essential element of this system is the use of modern technologies: wireless data exchange via GPRS and Internet.

2. The essence of monitoring

The aim of monitoring is above all the opportunity to determine current (especially in case of high environment inertia) or expected conditions of action. The key task of monitoring is data collection and transmission, as the data will form the basis for decision-making concerning the application of construction or operation options in order to ensure the best adjustment to environment (observed/expected changes).

Among many possibilities of realisation of the idea of automation in construction management (Zavadskas *et al.* 2008a), three of them, concerning automated data aquisition, deserve to be singled out:

- Web based management (Alshawi and Ingirge 2003; Kaklauskas *et al.* 2007a; Kaklauskas, Pruskus 2005) enabling data collection, analysis and distribution (including the processed data, e.g. with the use of simulation calculations) in the form of diagrams, graphs easier to perceive than source data, in case of complicated production systems facilitating the access to data on different management levels for different participants of the analysed process (client, user, engineer-consultant, supervision inspector etc.
- RFID (Navon 2007, 2008; Navon and Sacks 2007; Jang and Skibniewski 2008; Jang *et al.* 2008), the basic advantage of which seems to be the possibility of identifying people, materials, machines, construction elements and the like, what combined with possibilities of GPS system (or other method of determining object location) as a result enables to e.g. track changes in process efficiency and use 3, 4 and 5D simulation.
- Typical monitoring of environment and processes in progress based on chosen parameters (e.g. monitoring of rainfall, temperature, wind in a network of meteorological stations or temperature, stresses in concrete during maturing (Karlowski 2008) or operation (it seems very important to use the possibility of tracking changes in construction within the space of many years of operation – e.g. progress of corrosion and the like).

The discussed further example of monitoring application concerns the last possibility, when it comes to concreting process of massive construction. The above simple division does not exclude the possibility of combining a few options from the above list, e.g. to monitor the processes of damaged road surfaces (Chang *et al.* 2008) or the application of methods not included in the list (Zavadskas *et al.* 2006). At the same time the attention should be paid to the fact that very complicated technologies are not always essential for processes monitoring – e.g. while monitoring supplies of ready-mixed concrete, the identification of vehicles may be carried out by means of registration numbers, and labour intensity in different phases may be stated based on the recording of duration of stay of concrete mixer truck at key service points – it is not necessary to apply either RFID or GPS (Paslawski 2000, 2003b, 2005c).

3. State of knowledge in the field of monitoring maturing concrete

Thermal and volume changes caused by hydration heat of cement binder have a decisive role in the increase of stresses and occurrence of cracks and scratches. The first theoretical works in 1930s of Gloger and MacHenry concerned the influence of temperature fields and heat movement in massive constructions (Kiernozycki 2003). A few years later erection of great dams in the USA and USSR aroused growing interest in this issue followed by new publications and norms concerning technical conditions for designing. In these publications, authors resigned from determining thermal fields, focused on calculating technical stresses, drawn up formula determining values of own and forced stresses in massive concrete elements built as a result of self-heating of concrete. In the mid-1970s a large number of publications appeared concerning research on thermo-mechanical properties of concrete in the initial stages of structure development. In 1980 Brequel published his work about concrete maturing (Breugel 1980), where he presents a simplified method of analysis of forced thermal stresses of hardening concrete consisting in determining hardening concrete condition depending on creep strain. The issue of thermal influences has been widely discussed in technical literature and, although the first theoretical and experimental works were undertaken 70 years ago, a uniform theory of designing and technology of concrete elements production have not been drawn up so far. The main reason of that is an insufficient knowledge of the processes of structure development and relations with physical and thermo-mechanical properties of the hardening concrete. Such a situation results from many changing concrete features dependent on quality, environmental and technological factors which are difficult to determine in a uniform way owing to changes in hydration heat and different course of concrete maturing. In order to determine concrete parameters variables (designed concrete with expected properties), the research has been oriented towards:

- examination of the development of structure and its relations to concrete properties in different thermodynamic conditions,
- recording the process of changes in temperature and internal stresses from the moment of placing concrete mixture to the moment of time, when a proper strength of structure is achieved or when the structure is damaged.

The first research direction involves determination of physico-chemical relations based on laboratory works. The research is oriented towards determining the heat of cement hydration in different thermal conditions as well as drawing up methods preventing construction problems by following right phases of concreting with regard to technological conditions of concreting and drawing up proper prescriptions, applying additives and admixtures. The recording of the temperature changes in real conditions of concrete hardening and conducted laboratory research develop the basis for verifying theoretical solutions. Methods and results of research presented in literature contain many imperfections and mistakes, the presented data allow to conclude that the determination of relations between physico-chemical properties and thermal influence in different conditions is a difficult task. At the moment the research on the temperature fields is more and more often conducted by measuring the temperature of the interior and environment of the structure as well as measuring concrete stresses and shrinkage. The temperature measurement in concrete is usually conducted with the use of one detector, less often several (for example, 6 detectors used by Yesh, 2004) and one detector by Witakowski (2007)). Readings from a detector are sent to the recorder through a special wire. Measurement results from temperature detector are recorded in the recorder at freely programmed time intervals from 1s to 24h. Data collected in the recorder are read via the computer, which is periodically connected to the recorder for importing the data. The most modern solution of the above-mentioned method is the change in way of communication between the recorder and the computer, data transmission is wireless: via GSM network (Witakowski 2007) and RFID (Kaplinski 2007; Yesh 2004; Jang and Skibniewski 2008). Dynamic development of GSM network and its common application provides an unlimited range. The application of RFID communication provides a maximum 100-meter range and transmission occurs with the use of changing codes generated by a detector integrated with the recorder placed in concrete. The knowledge about monitoring of construction processes using GPRS and Internet has still not been spread sufficiently. There are great possibilities of developing and using this technology to collect, transmit and manage data and support decision-making during process management. The above review of literature shows that the currently used temperature measurement systems in the beginning phase of concrete maturing are not sufficient to entirely monitor and supervise concreting process. The system drawn up by Witakowski (2007), Yesh (2004), Tsenov (2007) have the following limitations:

- insufficient number of detectors does not provide us with a detailed information on temperature fields distribution – it is hard to determine temperature gradient which is responsible for the occurrence of thermal stresses;
- software used in the above-mentioned systems offers only the review of recorded temperature changes in time by tables and graphs.

4. Description of CONLI system

The principle of operation of the system consists in monitoring temperature in the beginning phase of concrete maturing by detectors placed in concrete and outside. Next the data is wirelessly sent via GSM network to people supervising building processes (concrete maturing process) via SMS message with information on concrete temperature for individual detectors. However, on www server, where the data is gathered in order to create a database, it is possible to generate visualization of temperature changes by isotherms in time. The system user is able to systematically monitor and to a less extent react (high level of thermal inertia of concrete mass) to any irregularities of concrete maturing – the user can undertake suitable actions for restoring proper course of the process. Because the possibility of controlling concreting of massive constructions is limited, it is particularly important to use passive component of flexibility (Paslawski 2008).

The presented system consists of two key elements (Fig. 1):

- Local recording by detectors placed in concrete, external temperature detector and recorder with GSM module which communicates with people supervising concreting via SMS messages and with www server on which measuring data is collected.
- Global recording by collecting the obtained from the recorder data on www server via GSM network.

Data collected in this way is recorded in a database and can be used for visualising the course of concreting. Apart from temperature, records regarding the examined structure (such as dimensions, concrete class) is also collected. Data received by www server is col-

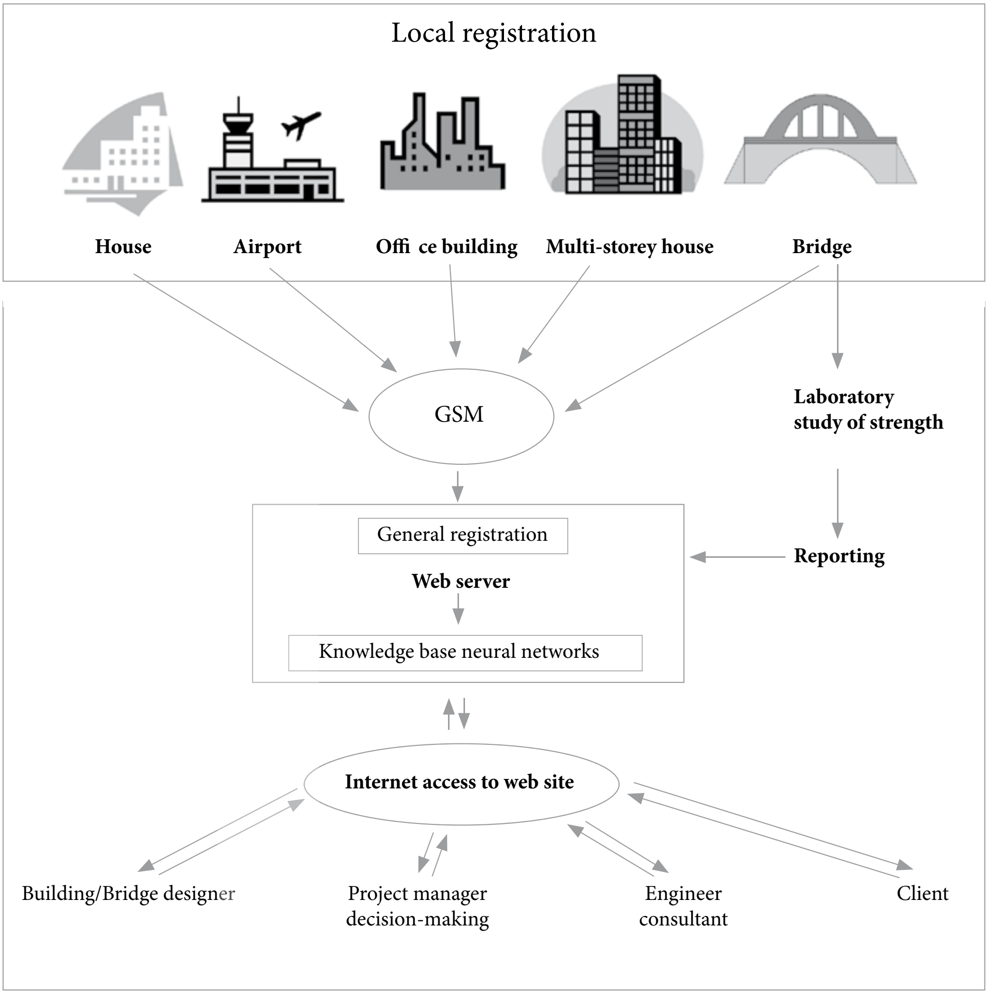

Fig. 1. General idea of CONLI system

lected and processed by specialist software which enables a quick update and an easy search of information. Data processing consists in:

- recording the results of measurement in a database,
- making data available to authorized people via authorization procedure (export of data to a spreadsheet, printouts in pdf and jpg format),
- creating visualization in the form of temperature fields (or compression strength and the like) changing in time.

GSM network using any operator is applied to send data from a building site – communication may take place in any area on condition the recorder is sent in the form of SMS message to people supervising concrete maturing process and as GPRS data to www server. Data collected by the server is accessible via Internet by means of any browser. The advantage of the accepted communication method via Internet and GSM network is: common application, wide range, low price, service simplicity and global software standard (Zavadskas *et al.* 2002). During monitoring of concreting a database of temperature measurements in the beginning phase of concrete maturing is continuously updated on the account of research conducted constantly. Temperature measurement in building begins with recording a new measuring building in a database. The activities consist in entering the information in the examined building into a database. The information is divided into basic (location of a building site, a period of construction, concrete class/es) and detailed information (dimensions of concrete element, number of detectors with their coordinates). The recorded in this way in a database task is assigned to measuring data stored according to a determined formula – model ensuring an appropriate selection of results. Data collected and recorded in a database is assigned to a particular location on a given building site according to a determined pattern. Pattern of data comprises information on a particular element with its defined geometric dimensions, produced in a certain time period, according to a specific formula of specified concrete mix, etc. Collected in this way measuring data together with additional information create a knowledge base which may be used to: optimization or/and simulation of concrete maturing processes, selection of appropriate concrete mix depending on concrete dimensions, required class of concrete for a specified season and predicted atmospheric conditions for obtaining the designed quality in concreting. The drawn up system is based on measuring and recording temperature from a dozen or so to several dozen detectors (at present there are maximum 32 detectors; however, owing to module structure, the system can be easily developed). Thanks to the application of a big number of measuring points, it is easy to determine temperature gradient what allows to assess risk, to estimate the degree of concrete adjustment to the expected requirements concerning proper strength homogeneity and check, if permissible risk of the occurrence of internal structural damage has not been exceeded (Kiernozycki, Slusarek 1996; Kiernozycki 2003). The discussed system is being constantly modernized and used for research conduct, the obtained results are stored in a database created specially for the system purpose. Software is a significant element of this type of system, as it allows not only to process the obtained data and review it online in the form of tables or graphs, but also to create a knowledge database and based on that formulate principles which permit to simulate and plan future processes. The design of a complex system is the answer to currently existing methods monitoring concrete maturing processes in the beginning phase of maturing. The integration of modern solutions of communication and transfer of GPS/GPRS data, Internet, databases enables the use of potential possibilities of facilitating building processes management.

5. Monitoring of concrete maturing process – theoretical basis

The aim of monitoring – as it has been already mentioned – is above all to provide information ensuring possibility of making right decisions in separate phases of production processes which give the opportunity to adjust flexibility options fit to construction conditions in the best possible way. Of course, a basic problem is to determine the function of criterion enabling to assess separate possible variants. In case of concreting such criteria may include:

- possibility of placing concrete mix properly (proper consolidation of concrete, surface levelling and the like),
- limiting the risk of cracking the element (above all in the beginning phase of concrete maturing, e.g. several dozen hours after moulding),
- ensuring the proper compression strength in a given period of time (e.g. on account of period of construction stripping or putting the construction into operation),
- ensuring proper long-lasting features of concrete (e.g. water permeability, absorbability, frost resistance, etc),
- limiting construction processes costs.

The enumerated criteria can be hierarchically arranged from Total Life Cycle viewpoint – e.g. the major role may be attributed to long-lasting features of construction (Paslawski 2001), on account of their role in expected operation costs. Multiciteria approach may also be applied (Banaitienė *et al.* 2008; Kaklauskas *et al.* 2006, 2007b; Su *et al.* 2006; Turskis *et al.* 2006; Zavadskas *et al.* 2006, 2007, 2008a) taking into account various meanings of separate criteria. The analysis of relations between the mentioned criteria shows the conflict of interests for different participants of investment processes in construction industry. Therefore, in the analysed example of the application of monitoring, the basic criterion was the control of concreting process which will reduce the risk of craking of the construction in the beginning phase of maturing. This problem is illustrated on Fig. 2.

Taking into account the complexity of the described effects in maturing concrete, it seems to be justified to apply hybrid advisory system based e.g. on neural networks, fuzzy logic and processes simulation. These separate elements complement each other – e.g. fuzzy logic allows to consider general relations, whereas neural network specifies numerical values (e.g. characterizing membership function based on learning from examples or coefficients enabling simulation), what ensures the accomplishment of synergy effect. Considering simulation model of maturing concrete, the attention should be paid to the necessity of simplifying complex relations (Kaplinski 1997). In the analysed case, in order to ensure the proper course of concrete maturing process in a massive construction, permissible temperature gradient was assumed which enabled to formulate decision-making principles in the following form:

$$\text{IF GradAi} > \text{GradCi THEN Fti}, \tag{1}$$

where: GradAi – actual gradient for localization at *i* [°C]; GradCi – critical gradient for localization at *i* [°C]; Fti – flexible tactic *i*.

6. CASE STUDY – monitoring of barite concrete maturing process

The system has been already used in practice many times – among different applications it was examined during monitoring of barite concrete maturing in massive construction. At the beginning of 2008 the system was used to supervise concreting process of a floor slab in Department of Radiotherapy in Regional Oncological Centre of Poznan. Basic dimensions of the slab were: width 12 m, length 27 m and thickness 1.9 m. Taking into account a great volume of a built-in concrete, the whole was divided into 3 parts with the dimensions of

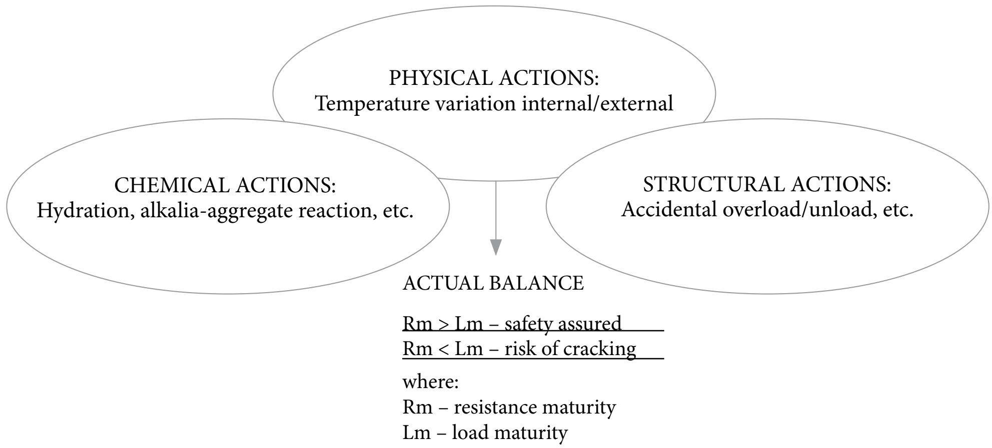

Fig. 2. General idea of resistance and load balancing in concrete maturing process

12 × 9 m. The concreting process of one block lasted about 20 h, the temperature of concrete mix was about 9–16 °C, and temperature of environment was changing from –6 to +2 °C depending on a time of the day. Temperature distribution and maximum gradient in chosen locations is presented in Fig. 3. In the analysed case maximum temperature of concrete has been reached 54 °C after 100 h and 15 min from the beginning of concreting. In order to ensure a proper course of concrete maturing in the examined massive construction, thermal gradients (vertical and horizontal) in separate sections were monitored and compared with critical gradient of 100 °C/m (Paslawski 1994). In the discussed example the following maximum internal gradients were reached:

- temperature difference between S1 and S2 detectors at a distance of 0.7 m ΔTa_1 = 10.56 °C after 76 h from the beginning of concreting

  => $GradA_1$ = 15 °C /m < GradC,
- temperature difference between S3 and B3 detectors at a distance of 6.3 m ΔTa_2 = 34.28 °C after 102 h from the beginning of concreting

  => $GradA_2$ = 5 °C /m < GradC,

on the borderline between concrete and outside environment:

- temperature difference between S3 and ABOVE detectors at a distance of 0.35 m ΔTa_3 = 37.36 °C after 108 h from the beginning of concreting

  => $GradA_3$ = 107 °C /m > GradC,
- temperature difference between B2 and OUTSIDE detectors at a distance of 0.35 m ΔTa_4 = 23.80 °C after 82 h from the beginning of concreting

  => $GradA_4$ = 68 °C /m < GradC.

In order to determine gradients, it was assumed that that temperature distribution between points is linear.

Exceeding critical gradient in section between S3 and ABOVE detectors ($GradA_3$ = 107 °C/m) resulted in initiating a proper flexibility tactics. The tactic consisted in heating up the upper surface of the slab with heater (3000 W power), what after the period of 9 h allowed to reduce the examined gradient to permissible value (93 °C/m).

Fig. 4 presents a vertical section of temperature distribution – both graphs were drawn at maximal temperature (54 °C). During the construction with the application of the described monitoring system of concreting process of the slab in Department of Radiotherapy other flexibility tactic was taken into consideration for ensuring the quality by means of protecting concrete against overinfluence of thermal stresses, e.g.:

- application of thermal insulating mat protecting against environment influence,
- heating bottom surface of concrete block.

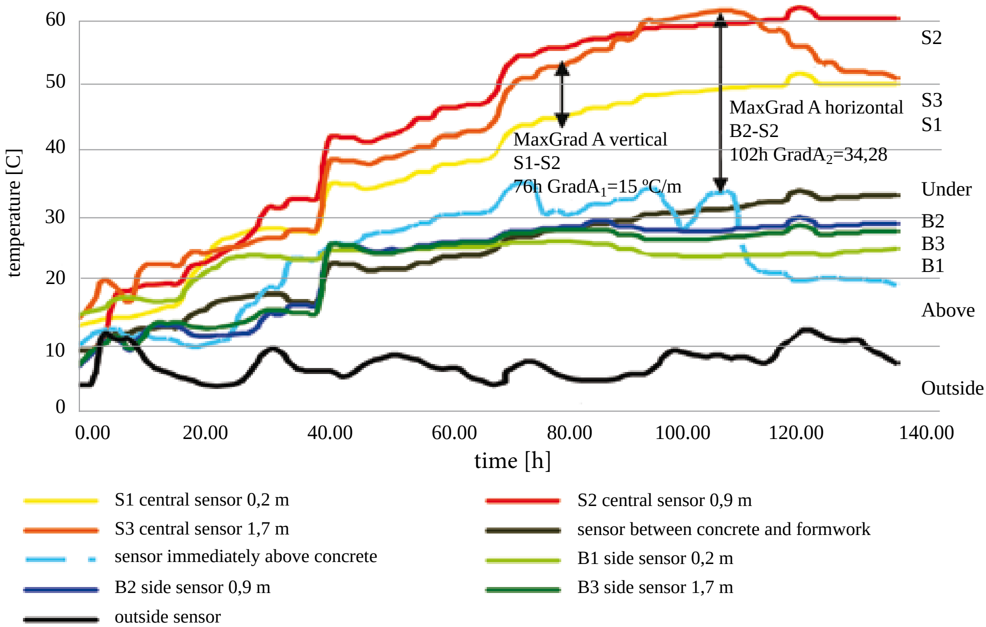

Fig. 3. Temperature distribution in the beginning phase of concrete bonding:

ABOVE – detector of temperature placed on the borderline of upper surface of concrete slab and environment
UNDER – detector of temperature placed on the borderline of lower surface of concrete slab and boarding
OUTSIDE – detector of temperature placed on the borderline of side surface of concrete slab and environment

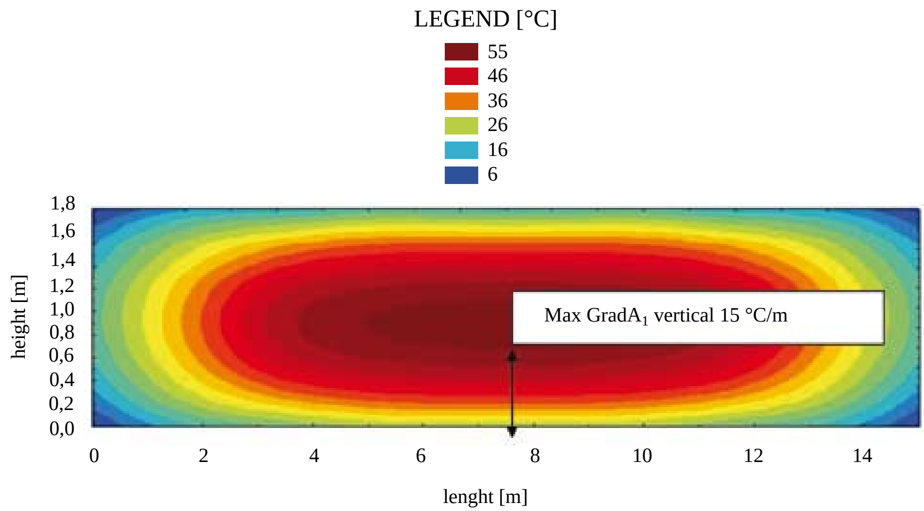

Fig. 4. Temperature distribution in the concrete block /vertical section

7. Conclusions

The presented theoretical principles and described example of application of CONLI monitoring system allow to draw the following conclusions:

1. The usefulness of the above CONLI system for monitoring the process of concrete maturing has been proved in practice on some building sites. The works being conducted at the moment of designing software for simulation and optimization of monitored concreting process are significant when designing a complex advisory hybrid system.
2. The use of such easily accessible and popular devices as GSM communication and Internet provides a space for potential application possibilities in the area of data gathering, transmission and storing as well as decision-making in real time, which enables to improve the system of ensuring quality during concreting.
3. The design of a complex system will enable to use both the results of laboratory research and measurements taken during construction of building structures, in design and building practice, which will increase the efficiency of procedures of construction processes on a building site. Development perspectives of the presented advisory system based on the following principles:

- Effectiveness and efficiency of the method require creating a right number of flexibility options (too many may generate the increase of investment costs).
- Modelling of the monitoring process is based on compromise between the limitation on the amount of information and credibility of results.
- Hybrid structure of advisory system enables to achieve synergy effect resulting from the interaction of different decision support methods (neural networks, fuzzy logic, simulation, etc.).

It seems to be justified to claim that while the implementation of robotics in building has not become quite common (on the level comparable to other fields of economics – e.g. car industry) and it is hard to expect quick change of this tendency, the monitoring of building processes and operating on this basis, hybrid advisory decision-making system may in a relatively short time allow for considerable improvements in the field of building processes management.

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STATYBOS PROCESŲ STEBĖSENA KINTANČIOJE APLINKOJE

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Santrauka

Statybos procesų trikdžiai yra ypač pastebimi dėl savo didelio kintamumo, neapibrėžtumo ir kompleksiškumo. Jie daro dilelę įtaką planavimo ir vykdymo procesams. Aplinkos, sukeliančios trikdžių, ir vykstančių procesų stebėsena sudaro galimybę lanksčiau valdyti procesus, o tai labai pagerina statybos kokybę užtikrinančių sistemų veikimo efektyvumą. Aprašyta CONLI sistema, kuri yra efektyvi priemonė, leidžianti realiuoju laiku keistis informacija tarp įvairių sprendimų priėmėjų (pavyzdžiui, statybos vadovų, techninės priežiūros inspektorių, investuotojų ir pan.), turinčių bevielę duomenų perdavimo sistemą ir hibridinę struktūrą. Sistema užtikrina prieigą prie įvairios apimties informacijos ir garantuoja reikiamą jos konfidencialumą.

Reikšminiai žodžiai: kontrolė, statybos valdymas, statybos procesas, lankstumas, betonavimas.

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