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MONITORING OF BUILDINGS IN SELECTED STAGES OF SERVICE LIFE (SL) – CASE STUDIES

MONITORING OBIEKTÓW BUDOWLANYCH W WYBRANYCH ETAPACH CYKLU ŻYCIA (SL)

A b s t r a c t

The paper discusses the functions and objectives of systems, used for a building's monitoring process, through the subsequent stages of a building's service life. The authors present the result of research regarding the monitoring of two buildings undergoing refurbishment: an industrial hall and a multi-storey general use building. Refurbishment of the industrial building included upgrading an existing production line, associated with an increased technological load. In the general-use building the foundations were strengthened in connection with the construction of a new multi-storey building in the immediate vicinity. The process of reinforcing footings, or – pilings – was monitored, as well as the preservation of an existing building, during the course of the construction of the new building.

Keywords: structural monitoring, service life of a building, safety of use

S t r e s z c z e n i e

W artykule omówiono funkcje oraz cele monitoringu, wyodrębniono i scharakteryzowano elementy systemów monitorujących. Podano zakres procesu monitorowania w kolejnych fazach cyklu życia obiektu budowlanego. Autorzy przedstawili wyniki badań dotyczące monitoringu dwóch obiektów poddanych modernizacji: hali przemysłowej oraz budynku wielokondygnacyjnego użyteczności publicznej. Modernizacja budynku przemysłowego polegała na unowocześnieniu istniejącej linii produkcyjnej, co związane jest ze zwiększeniem obciążenia technologicznego. W obiekcie użyteczności publicznej wzmacniano fundamenty w związku z posadowieniem w bezpośrednim sąsiedztwie nowego budynku wielokondygnacyjnego. Monitorowano proces wzmacniania ław fundamentów (palowania) oraz zachowanie się konstrukcji istniejącego obiektu w trakcie realizacji nowo wznoszonego budynku.

Słowa kluczowe: monitoring konstrukcji, cykl życia obiektu, bezpieczeństwo użytkowania

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1. Introduction

Monitoring (*monitor*, Latin: *admonitory*) denotes the regular qualitative and quantitative measurement of indicators (parameters) of an examined phenomenon as well as information about deviations from normal conditions. Monitoring has two functions: observation and warning. The intensive development of electronics, computer science and the Internet have led to monitoring systems being used in almost all areas of human activity. Construction is an area of the economy, in which monitoring also plays an increasingly important role. The objective of these studies is primarily to enhance safety at every stage of the service life (SL) of a building [8] and the sustainability of buildings. Information collected during the monitoring process can be helpful when choosing the appropriate action in the event of any adverse impact from certain factors (phenomena) on the building process or the safety status of the building. The monitoring system , regardless of the area of its application, consists of the following elements [1, 2, 5, 6, 13]:

– The monitored construction or its parts: foundations, floor slabs, walls, roof trusses, etc.;
– Sensors – for measurement of studied values: deformations, displacements, strain, pressure, temperature, etc. These are devices that convert the measured parameters into a different scale, usually electricity, which can be easily transmitted. The type of measuring apparatus and its location should be determined individually and adapted to monitoring conditions. New capacities create more accurate apparatuses and GPS (Global Positioning System) methods. This is particularly true of surveying techniques;
– Data acquisition system – frequency measurements, resolution of measured signals, application filters, etc.;
– Transfer and data input in the computer centre with all the necessary software to enable the processing of signals, analysis of the results obtained and a final evaluation of technical conditions. Gathering information from a variety of measurement systems in the centre enables more in-depth analysis.

In modern systems, it is possible combine several sensors into one measuring system, which enables the simultaneous recording of multiple physical values. Such an arrangement is called a microsystem or measuring *mote* (Fig. 1). [13] It may be fully autonomous and communicate with the central laboratory by using wireless connectivity.

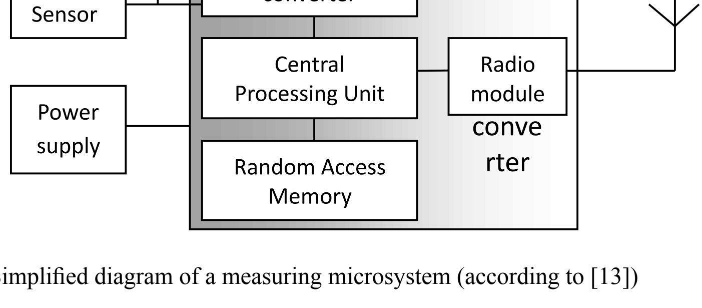

Fig. 1. Simplified diagram of a measuring microsystem (according to [13])

2. Monitoring of the phases of a building's service life (SL)

Monitoring – depending on needs – may be carried out at all stages of the service life project design, implementation, use and demolition.

During the development phase of the project, compliance with requirements on the project tab regarding properties during the period of use is controlled by, among other things. Moreover, the information describing the detailed design and other documents relevant to the assessment of the service life of the test results is checked and an evaluation of the performance of materials and components provided by the manufacturer is controlled. During the development of the project the completeness of the information concerning SAHP is also evaluated.

Monitoring at this stage means control of the development of the desired effects of the project, the comparison to the existing norms and technical specifications and standards as well, and, if necessary, taking indispensable corrective actions.

During the implementation phase the monitoring may refer to different aspects: the results of materials research (if carried out), changes in specifications and technical documentation, weather conditions, etc., In the case of work carried out during the winter, some construction processes require monitoring and evaluation of the regularity operations in real time. An example of where it is necessary to use continuous monitoring is concrete work, during which maintenance of the temperature and humidity of the setting concrete within well-defined borders is imperative [13]. Information about the possible need for revision of care activities is reported to supervisory centres in real time.

During the usage phase, the longest phase of the building's service life, monitoring is focused on certain types of potential construction risk (called Structural Health Monitoring, or – SHM) [1, 11]. The greater part of this research arises from the provisions of the law, such as the Ministry of Interior Regulations on the fire protection of buildings [10] or the regulation of the Minister of Infrastructure [9] introducing the obligation of monitoring in terms of the fulfilment of the conditions ensuring that borderline limit values for capacity and usage are not exceeded. The latter applies in particular to the regulation of buildings with rooms designed to accommodate a significant number of people, such as performing arts halls, sports arenas and exhibition grounds. This type of monitoring is carried out by specialized systems developed for this purpose [11, 13]. Monitoring systems, also known as warning alarm systems, are based on the results of measurements of the values of the condition of the building and its surroundings, or, more specifically, on information relevant to the type of potential threat. The greatest of these are the relative linear and angular displacements, temperature, strain, acceleration, and others. For most of these parameters permissible limit values – u_{dop} and borderline limit values u_{gr} (Fig. 2) should be determined. The permissible limit values (warning) are understood as those that do not directly threaten the safety of the design; exceeding them indicates the urgent need for the analysis of the causes of their emergence and prevention of further deterioration [12]. Exceeding the borderline limit values can pose the danger of collapse.

Demolition phase – this is the last stage in the service life of the building. Depending on the location of the building and the type of demolition, e.g. selective demolition, this work can be very dangerous and may require specific security measures and continuous monitoring.

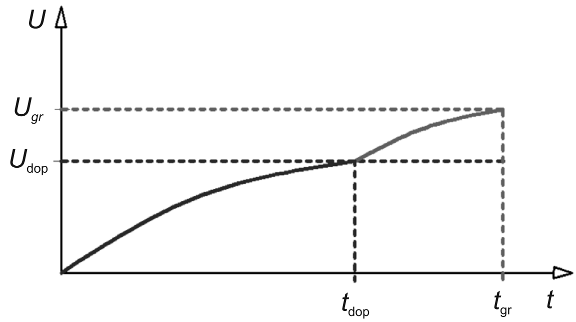

Fig. 2. Changes in value *u* as a function of time *t*

3. Monitoring of buildings undergoing refurbishment and modernisation

Refurbishment and modernization work concerns existing buildings up to several decades old. The aim of this work is renewal or adaptation to contemporary or new requirements: commercial, technical, environmental, production, etc. Often users of these buildings do not have any technical documentation; suitability for the intended use is assessed on the basis of individual exposure. Established theoretical models of construction upgrades are studied in actual working conditions by means of selected measurements of physical quantities, i.e. through monitoring.

3.1. Example 1. Monitoring test loads

The subject of this research is the construction of slab in an industrial building opened for use in 1972. The production line in this building was modernized. Three steel tanks with a capacity of 20 m^3 each were designated to replace existing 4-oak vats with a capacity of 12 m^3. The vats distributed load evenly on the slab, while the tanks distribute load in the form of concentrated forces; each tank is based on four supports. The investor has fragmentary construction documentation. Reinforcement in spans of load-bearing was established on the basis of the exposure. The strength of concrete was defined in sclerometric research. The results of static analysis indicate that the tanks with a capacity of 20 m^3 can be positioned on the floor in specific locations, as shown in Fig. 3.

Before submitting the upgraded technological line, the designers of the project citied the execution of test loads as an absolute condition. The comparison of measured strains of designated points with theoretical values would determine whether the assumptions regarding the calculations were relevant to real conditions.

The test load consisted of filling the tanks with water and measuring, at specified intervals, the deformation of slab elements. From static analysis, it appears that the greatest deflection occurs at the back of the tanks; the deflection in the rib marked '1' is approximately 7.6 mm [7].

Measuring points in the form of mirrors located in certain places on the slab. Under every measuring point in the basement floor, benchmark bases were located. Four measuring points were installed. Their location is marked on Fig. 3 with numbers '1', '2', '3' and '4'. Altitude measurements were made using tacheometry methods. The difference in the distance between the 'mirror' benchmark, mounted in the tested element, and the base benchmark was determined during two different measuring periods; before filling the tanks and during the subsequent phases of filling indicating the increase in the deformation of the tested element, i.e. ribs.

The test load was carried out according to the following course of action:
- filling tank *Z*1 wit water,
- taking readings of the deformation at measuring points,
- filling tank *Z*3 situated at the adjacent grid,
- filling tank 2 and measuring strain,
- waiting 24 hours and re measuring the deformation,
- emptying all of the tanks and measuring the deformations.
- The results of the measurements are shown in the following table.

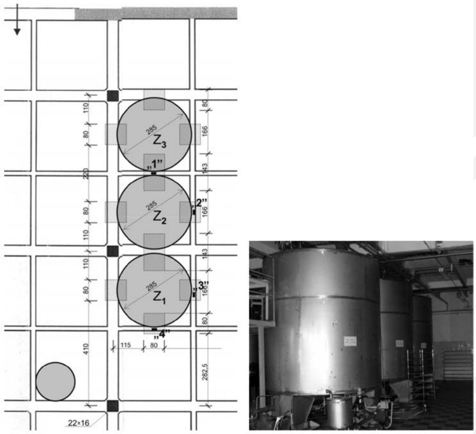

Fig. 3. The proposed schema of location tanks. View of the tanks positioned on the slab

Table 1

The extent of deformation of measuring points of structural elements of the slab[mm]

State of tanks	Measuring points				Date of measurement
	,1'	,2'	,3'	,4'	
All emptied	0.0	0.0	0.0	0.0	14 January
FIlled Z_1	0.1	0.3	0.8	1.0	15 January
Filled Z_3 (Z_1 also)	1.2	1.8	1.1	1.0	16 January
Filled Z_2 (Z_1 i Z_3 also)	1.7	2.0	1.5	1.2	17 January
All filled	1.7	1.9	1.6	1.5	18 January
All emptied	0.2	0.3	0.8	0.3	19 January

The extent of the distortion in the test of structural elements in the slab is definitely less than that specified on the basis of numerical analysis. At point ‘1’ the maximum deflection was 1.7 mm. These data show that the assumptions for the analysis were correctly made and indicate the maintenance of a significant level of safety of the slab structure. The basis for a positive evaluation of the suitability of the structure subjected to a test –load is the confirmation of the assumption about the elastic behavior of the structure [6]. This is indicated by the fact that a slight deflection of the assets remained after removing the test load. At point ‘1’ the permanent deflection was 0.2 mm. The location of the tanks on the slab given the current technical condition of the structure will not cause a threat to its integrity.

3.2. Example no. 2. Monitoringof deformation while securing the foundations of public utility building

The subject of research is building C-4, concerning a five-storey basement, located in the complex of classroom buildings of AGH in Cracow. The design layout of the building is oblong: full ceramic brick walls, thick-ribbed slabs. The building was opened for use in the 1960s. In its immediate vicinity there is a new building, the Energy Centre (C.E.) which was under construction at the time of writing (Fig. 4). C.E. comprised of five floors above ground, and one underground. The level of the foundation of the newly designed building is approximately 250 cm below the bottom of the footing of C-4. Before the start of the excavations under the widely-spaced foundations of the new building, securing work along the top wall of the existing building C-4 was carried out. Fig. 5 shows a cross-section of the foundations of both buildings. This work was carried out by the ‘jet grouting’ method – that is, injection jetting consisting of mixing the soil with grout and extruding it under high pressure. The project provided for the execution of about 80 injection columns. The following parameters of the injection process were assumed:
- Drilling diameter of 114 mm to 150 mm,
- Grout density of 1.46 g/cm^3 to 1.61 g/cm^3 (c/w from 1.0 to 1.5),
- Compression medium to a pressure of 350–400 atm,
- Lath lifting speed from 4 cm/7 to 4 cm/3s,
- Length of the column: – 12–14 m,
- Spacing of columns: – 600 mm.

The columns were carried out in so-called floating order; i.e. every 4th column in a row was injected, with no more than 5 columns completed per day. This „order” was intended to minimise the effect of short-term loosening of land until the binding of the grout injection.

Due to the complexity of the C-4 building work, monitoring was undertaken. In the basement level and the ground 8 benchmarks were mounted. The location of these benchmarks is shown in Fig. 4. In the technical design of the C.E. building, the permissible deformation of foundations was defined as: u_{dop} = 20 mm.

In the first phase of the protective work, the following foundation-pile parameters were assumed: injection pressure p_{in} = 300 at, forming a single pile – t_{in} = 15 min. During the protective work measurements of the deformation of the walls were taken in every 24 hours.

After completing approximately 26 piles, a 'push' of the foundation of building C-4 was observed. The maximum deformation measured at benchmark no. 5 was $u_5 = \sim 20$ mm. At the same time, visible scratched appeared on the longitudinal walls (Fig. 6). After analysing the results of previous monitoring and consultation with the design office, it was decided that the parameters for completing the remaining columns were to be changed: $p_{in} = 250$ at, forming time– $t_{in} = 40$ min. Subsequent readings of deformation of the benchmarks confirmed the validity of the decision: the deformation of the walls decreased; at the end of the protective work the deformation at benchmark no. 5 was: $u_5 = 12$ mm. Ten months after the end of work it was $u_5 = 5$ mm, i.e. less than u_{dop}.

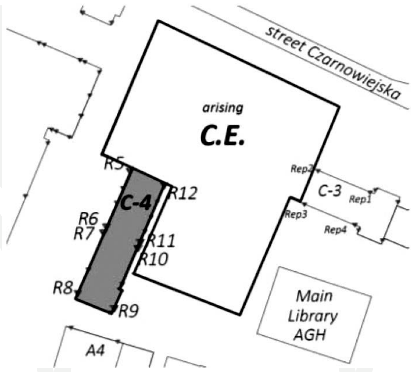

Fig 4. Projected position of buildings C-4 and C.E. *Ri* – benchmark number

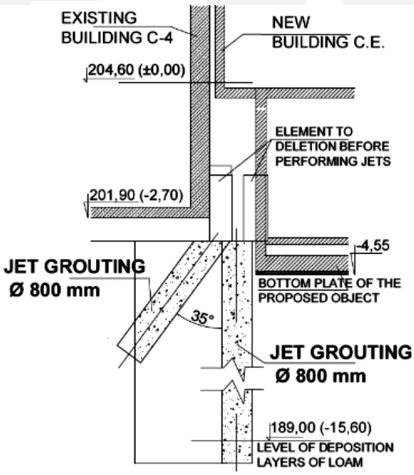

Fig 5. Cross-section of the foundation of buildings C-4 and C.E

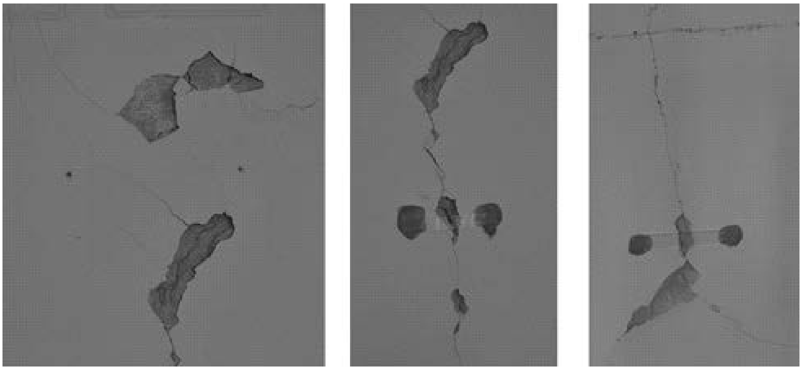

Fig. 6. Examples of visible scratched in C-4 building

4. Conclusions

During refurbishment work with limited design documentation available to the designer and, in particular, when refurbishment of a building is associated with an increase in usage parameters, the test-load of a structure and monitoring enable the deformation of the safety level of a building.

Problems associated with constructing buildings in areas with a dense downtown structure and the consequent, nature of impacts on adjacent buildings, the reasons for emergence of risks and ways to counter them are widely known. However, the individual character of each building, the variability of natural field conditions, related to geological-engineering and hydrogeological conditions and external environmental conditions mean that while erecting buildings, despite the care taken in the preparation of projects, we should anticipate unexpected reactions, as in example no. 2.

Based on an analysis of the results from the aforementioned examples, it can be concluded that the use of the monitoring enables the determination of the correctness of the assumptions in the proposed solution in real time, and, in the case of deviations, help in making appropriate decisions regarding further action.

Monitoring enables the updating of the assumptions, which in turn contributes to the safety of the monitored building.

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