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INVESTIGATING THE IMPACT OF TEMPERATURE CHANGES, MATERIAL AGING, AND SERVICE LOAD ON THE STRAIN OF A REINFORCED CONCRETE CONSTRUCTION

BADANIE WPŁYWU ZMIAN TEMPERATURY, STARZENIA MATERIAŁU I OBCIĄŻEŃ EKSPLOATACYJNYCH NA ODKSZTAŁCENIA KONSTRUKCJI ŻELBETOWEJ

Intensive exploitation of coal beds in the Upper Silesia Coal Basin led to the degradation of the Katowice-Muchowiec civilian/military airport. As a result, it became necessary to adapt the Pyrzowice military airport for use as a public transport facility. This involved reconstruction of a hangar located at the airport. As part of this process, a new hangar slab was constructed, designed in such a way as to bear the load of passenger aircraft. In the area of the greatest wheel load to the slab, three strain rosettes were installed for the purpose of monitoring the slab strain. The mointoring process – which has been automatically conducted for almost three years now – revealed deformations resulting from service load, the aging of reinforced concrete, and changes of its temperature.

Keywords: building engineering, metrology

Intensywna eksploatacja górnośląskich złóż węgla doprowadziła do degradacji cywilno-wojskowego lotniska Katowice-Muchowiec. W związku z tym, wynikła konieczność przystosowania do celów komunikacyjnych lotniska wojskowego w Pyrzowicach, w tym przebudowy znajdującego się na jego terenie hangaru. W ramach przebudowy wykonano nową posadzkę, zdolną przenosić ciężar samolotów pasażerskich. W posadzce tej, w rejonie występowania największych nacisków zainstalowano 3 rozety tensometryczne w celu monitorowania jej odkształceń. Monitorowanie to, prowadzone w sposób automatyczny już niemal 3 lata, wykazało występowanie odkształceń będących skutkiem obciążeń eksploatacyjnych, starzenia się żelbetu oraz zmian jego temperatury.

Słowa kluczowe: budownictwo, metrologia

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1. Introduction

In 1926, in the district of Muchowiec in Katowice, the Silesian Voivodeship District of the Airborne Defence League commissioned the construction of an airport which was subsequently leased to the then Ministry of Transport (pol. Ministerstwo Komunikacji). This was the airport of Muchowiec (*Muchowiec...*). Since 1929, it was used for civilian purposes, being the place from which scheduled flights to Warsaw, Vienna, and even nearby Kraków were operated. After 1958, due to mining damage (including the damage to the concrete runway), regular scheduled flights were no longer held. Thus, the Upper Silesian urban area was deprived of scheduled flights until 1966, when the inaugural civilian flight to Warsaw was operated from the military airport in Pyrzowice (*Pyrzowice...*), 30 km north of Katowice. The history of this particular airport is also complex. It was built by the occupying German forces as an emergency airport. After the second world war, it was taken over by the Soviet Army, and subsequently handed over to 39th Fighter Aviation Regiment of the Polish Air Defence Forces. From 1966 to 2000, the airport functioned as both a military and civilian transport airport. Ultimately, it became a fully civilian facility. After 2000 – already as the Katowice International Airport – it was significantly expanded. Some previous constructions still located at the airport are the runway from 1964, and the imposing hangar built around 1948.

The hangar is a hall whose dimensions are 84×42.5 m. It is surrounded by maintenance rooms on three sides. Thus, it can simultaneously store two aircraft of the size of Airbus A320, or Boeing 737. The airport management decided to modernize the hangar so that passenger aircraft (mostly of the type specified above) could be serviced there. The hangar slab was designed with the assumption that it would support fighter planes whose take-off weight does not exceed 9,100 kg (MiG-19). The weight of an Airbus A320-type aircraft (without passengers, cargo, and fuel) is 42,400 kg (*A320...*), so it exceeds the aforementioned limit several times. Five samples of the slab were collected so that its strength could be determined (at least approximately). The diameter of this cylindrical samples was 122÷125 mm. Figure 1 shows a photograph of one of the samples.

The collected samples were not homogenous. They contained the upper, hardened layer of the slab (visible in the lower part of the photograph). They also differed with respect to their height, which meant that the thickness of the slab was not the same in every spot. For the purpose of the research, three samples were chosen, after prior preparations. Their size corresponded to the requirements of the norm (PN-EN 12390-1, 2002). Then, the strength of the samples was tested in accordance with the norm (PN-EN 12390-3, 2002). The tests were carried out by means of the Instron 8500 test machine, used for testing brittle materials.The determined values of the three samples' strength under uni-axial compression (R_c) were: 79, 29, and 30 MPa. Varied slab thickness, significant differences in concrete strength, and, above all, the damages to the slab resulting from the wheel load (Fig. 2) – these were the reasons for which it was decided that the hangar slab would be replaced, at least partially.

2. The plan of a new hangar slab

Figure 3 presents a simplified plan of the hangar slab after the hangar modernization (the eastern part; the western part of the hangar is a mirror image of the eastern one). As part of the modernization process, the roof of the hangar was also renovated – however, it was not reconstructed in a way that would make it possible to shelter the whole aircraft within the hangar.

Fig. 1. A sample of the hangar slab

Fig. 2. The hangar slab with visible damages

The hangar is too low for the fins of aircraft even smaller than Airbus A320. Therefore, it was assumed that, during maintenance works, the control surfaces and the rear part of the fuselage would protrude through the gate.

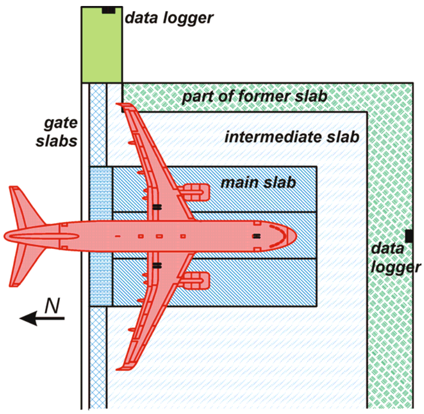

Fig. 3. The plan of the hangar slab after modernization – the eastern part

All the slabs – the main slab, the intermediate slab, and the gate slabs – were made of the same concrete. They also have the same thickness (30 cm), and rest on the same substructure, being linked to it with a separating layer. The slabs differ only with respect to the reinforcement. The main slab, whose dimensions were 26.25 × 18 m, was constructed as 3 separate slabs – each of them 6 m wide – with expansion joint gaps. The two-level cross reinforcement of the slabs was made of rods whose diameter was 16 mm, placed with various density (usually every 16 cm).

2. The purpose of installing research equipment in the hangar and the choice of this equipment

The purpose of installing the measuring equipment in the hangar – and of carrying out measurements by means of this equipment – is determining the strain of the eastern main slab during its standard exploitation. The strain in question can be the result of the unrestrained shrinkage (chemical shrinkage, the so-called contraction) and of the drying up (*Budownictwo*..., p. 377) of the concrete used to build the slab. Another causes of the strain can be temperature changes, as well as the wheel load from the aircraft serviced in the hangar. Obviously, the impact of the latter is going to be visible particularly in these spots where the wheels of the three legs of the aircraft landing gear rest upon the slab. According to the adopted procedures, the aircraft moved into the hangar should assume a strictly defined position, but only in relation to the wheels of the nose leg. The parking place of the wheels of the main landing gear (wing landing gear) is determined only approximately, as it is not required that the axis of the fuselage of the aircraft moved into the hangar overlap the axis of the main slab (Fig. 3); it can be diverted by several degrees.

The strain of building structures is usually measured manually, by means of strain gauges, such as those described by (Gustkiewicz, 2003, p. 58). They are equipped with a micrometer screw or a dial indicator, which ensure precise measurement of changes in the distance between benchmarks installed permanently on the surface of the investigated structure. The prescribed exploitation of the hangar slab forbids installing any instruments or elements on the slab surface. Thus, the only possible way of installing the instruments for strain measurements, i.e. strain gauges, was to insert them into a semisolid concrete mix, at the stage of the main slab construction. Thus, the strain gauges, once installed, cannot be serviced, exchanged, or adjusted – which is why they have to be highly reliable and stable when it comes to metrological parameters. Such features are displayed by vibrating wire strain gauges, which have been used in Poland for over 50 years to evaluate mining damage (Gustkiewicz, 1962). Due to the fact that they have been in use for so long, their usefulness when it comes to measurements performed in places with limited access or no access at all was established (Gustkiewicz, 2003).

3. Installing strain rosettes in the main (eastern) slab of the hangar

For the purpose of the measurements, 9 vibrating wire strain gauges (Kanciruk, 2012, p. 61) were used, as well as 3 thermistors for measuring the temperature of the reinforced concrete, and 2 electronic meters – data loggers (Kanciruk, 2012, p. 91). The electronic meters were also equipped with thermistors for measuring the temperature of the air inside the hangar. Vibrating wire strain gauges were arranged in the shape of three equilateral rosettes. Each of the rosettes was inserted into the slab, 4÷6 cm above its bottom surface (adjoining the separating layer), in the spots for which the maximum load was predicted – i.e. under the wheels of the landing gear of the serviced Airbus A320 aircraft (Fig. 4).

Unfortunately, after the construction was finished, the prescribed position of the aircraft in the hangar was changed. At present, the aircraft is moved into the hangar in such a way that the leg wheels do not come to a halt above the installed rosettes, but ca. 2 meters away from these points, having passed over them (as seen from the nose cone of an aircraft – cf. Fig. 5). Thus, the

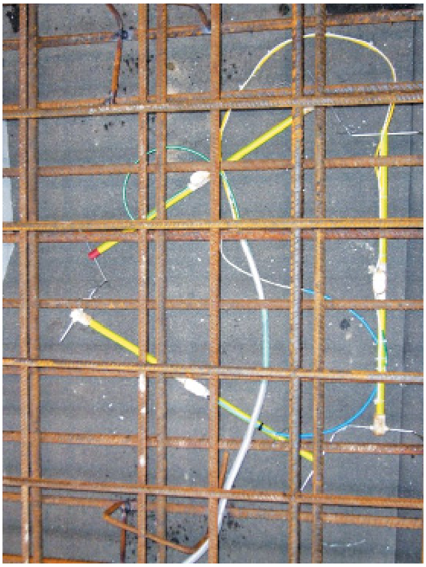

Fig. 4. A rosette installed in the area of the load of the wheels of the main left leg

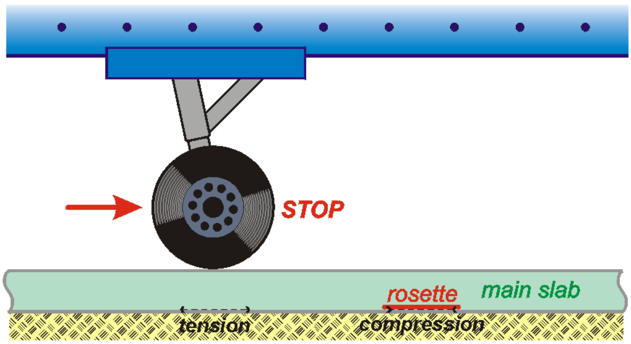

Fig. 5. The position of the wheels of the aircraft landing gear in relation to the rosettes

strain calculated on the basis of the readings of the strain gauges have to be smaller than in the spots of wheel resistance, and have a different sign (compression instead of tension).

4. Measurements and recording of the results. Interpretation of the obtained data

All the strain gauges, as well as the thermistors of the rosettes, were connected to 2 meters – data loggers. The latter were programmed in such a way as to register the measured quantities 50 times during every 24 hours. For identification purposes, the strain gauges were marked with colorful pieces of cloth which were put on the wires (Fig. 4). Accordingly, on the graph below, the curves representing the measurement data obtained by means of these strain gauges have adequate colors. Figure 6 presents the values of the strain calculated on the basis of the readings displayed by particular strain gauges of the left rosette.

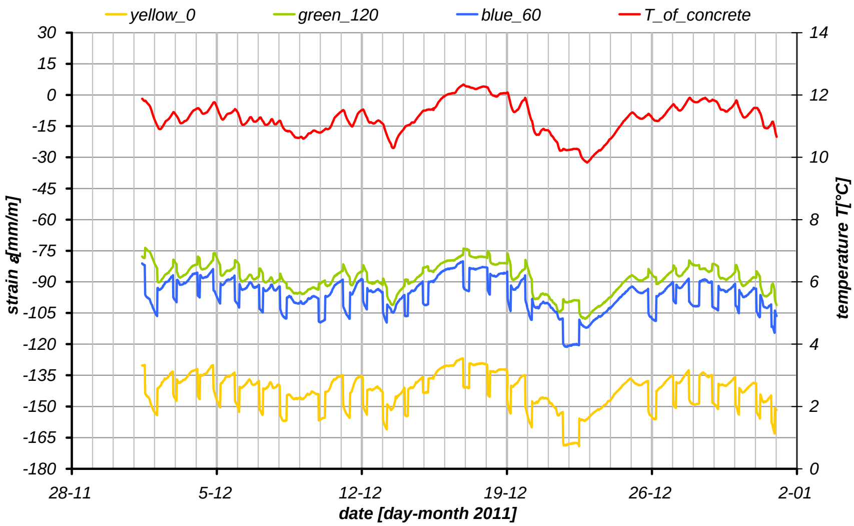

Fig. 6. The left rosette. The values of the strain calculated on the basis of the readings of particular strain gaues (the *„yellow”, „green”,* and *„blue”* one); the temperature of the bottom layer of the slab (*concrete temperature*). December 2011

As illustrated by the graph, all the strain gauges react to changes in the temperature of the concrete, and to service load. Every time an aircraft is moved into or out of the hangar, the strain of the slab changes suddenly. With a special software, these strain values can be established and, on their basis, the values of the main strains and their directions can be determined. Figure 7 presents the calculated values of the main strains for each situation when an aircraft was stationed in the hangar in December 2011.

In order to present both the values and the directions of the main strains of the slab in the spots where the left and right rosette were installed (in the vicinity of the wheels of the main legs of the aircraft), the following way of their graphical interpretation was developed (Figs 8-10).

Figure 8 presents the outline of an aircraft. The edges of the slabs from which the main slab was built are also shown, as well as the gate. In front of the wheels of the left main landing gear (in the direction of the nose cone), two right angle crossing segments were placed. The rosette is located precisely in the spot where they cross. The longer segment, marked with the purple line, represents the direction of the minimum strains – the compressive ones; its length corresponds to the value of these strains. The shorter segment represents the maximum strains – the tensile ones. Similarly, the segments marked with the green and the blue line represent the main strains measured by the rosette installed in front of the wheels of the right main landing gear. As can easily be seen, the compressive strains are directed towards the middle of the main slab. This is

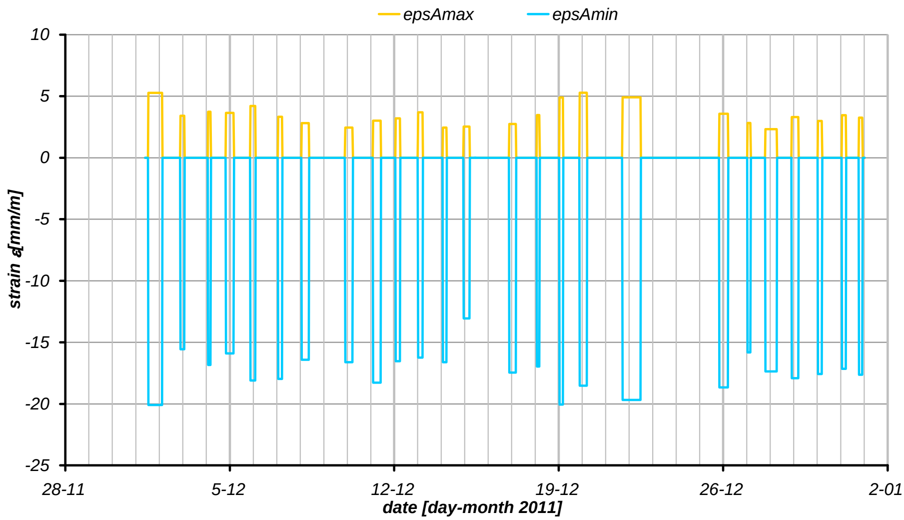

Fig. 7. The left rosette. The values of the main strains: the maximum (*epsAmax*) and the minimum (*epsAmin*) ones, caused by the aircraft load to the main slab. December 2011

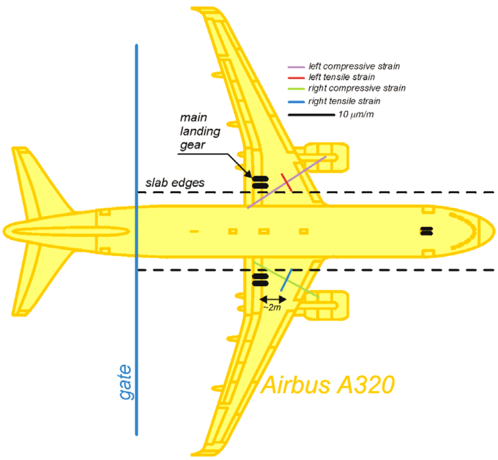

Fig. 8. A graphical interpretation of the measurement results: the values and the main strains for a particular recorded case of stationing an aircraft in the hangar

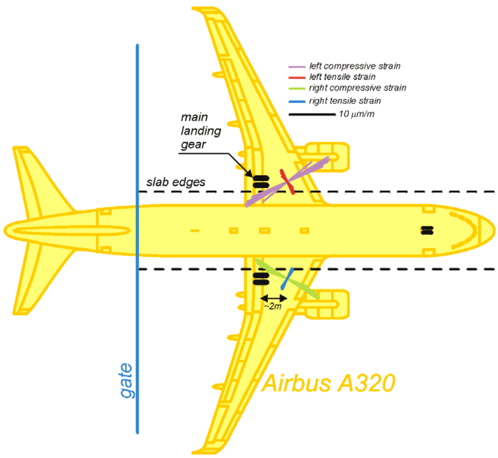

Fig. 9. A graphical interpretation of the measurement results: the values and the main strains for all the recorded cases of stationing an aircraft in the hangar in December 2011

due to the fact that the width of each particular slab – as was mentioned below – is 6 m, and the spacing between the main legs of the Airbus A320 aircraft is ca. 7.5 m. As a result, the peripheral slabs of the main slab bend towards the main slab axis. Figure 9 presents all the recorded cases of an aircraft stationed in the hangar in December 2011.

After adding the time axis to Figure 9, and removing the aircraft outline, the lines representing the slab edges, and the gate, we obtain a simple timing diagram depicting the values and directions of main strains, calculated on the basis of the readings of strain gauges in both rosettes (Fig. 10). The diagram takes account of all the cases of stationing an aircraft in the hangar in December 2011. The spots where the pairs of segments cross correspond (time-wise) to the midtimes of the periods of aircraft stationing in the hangar.

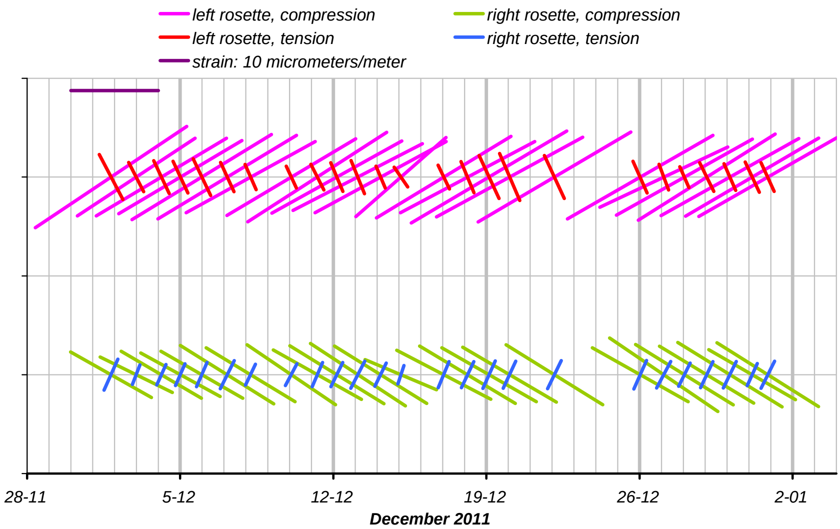

Fig. 10. The main strains of the constituent slabs making up the main slab, in the spots where the rosettes were located, for each case of stationing an aircraft in the hangar in December 2011

Just like in Figure 10, the diagrams were created for each consecutive month of the observation process, from June 2011 to April 2014. Measurements of the slab strains are still being performed.

The compressive strains ε, measured with the rosettes located in the vicinity of the spot where the load from the wheels of the main legs is exerted, reached the values of ca. 20 µm/m (Figs 5 and 7). In order to evaluate the tensile strains occurring in the spot of the wheel load, a computer simulation was performed (Kanciruk, 2012, p. 183). From the results of the simulation, one can infer that the value of these strains is even 12 times greater (module-wise) than the measured compressive strains, and exceeds 240 µm/m. The tensile tests performed on the concrete samples (Kanciruk, 2009, p. 126) indicate that the modulus of elasticity E of the concrete of the same class as the concrete used to build the hangar slabs is ca. 30 GPa, and its strength R_r slightly exceeds the value of 3 MPa. Thus, the maximum tensile strains of the concrete in the spot with no access for observation:

$$\sigma = E\varepsilon \rightarrow \sigma = 30 \text{ MPa} \times 240 \text{ µm/m} \rightarrow \sigma = 7.2 \text{ MPa}$$

exceed the value of 3 MPa, which definitely results in scratches.

To verify the model, it would be necessary to position an aircraft in an unprocedural manner, with the wheels of the main legs placed exactly above the rosettes. However, this is impossible, as pushing an aircraft further into the hangar could result in a collision of the fin with the roof and the gate (Fig. 3). Out of all the 765 cases of stationing an aircraft in the hangar recorded so far (i.e. until the 29th of April, 2014), only in one case, and only for the duration of one measurement cycle repeated every 30 minutes, the positioning of the aircraft was probably different than the positioning specified in the regulations. Therefore, the rosettes revealed strains, extending along the slabs, which were 3 times (the left rosette) and 4.6 times (the right rosette) greater module-wise than the subsequent compressive strains. This is suggested by the fact that the aircraft was moved further than usual inside the hangar – albeit in a manner that was not risky.

The graph in Figure 10 represents the strains of the slabs at the time when these strains reached the maximum values, module-wise. Figure 11 shows the values of the strains for all the cases of stationing aircraft in the hangar. It can be seen that, during the first six months of exploiting the hangar, the values of the strains tended to rise module-wise. Subsequently, they tended to decrease, which would ultimately result in a state of stability. Surely, there may be several factors that explain why the values of the strains change, and why they reach stability. One of them is the fact that the foundation of the slab subsides. However, particular attention should be paid to another potential reason, i.e. the fact that an airport apron, whose area is 11 ha and thickness is 30 cm, was built in the vicinity of the hangar. The weight of the airport apron has probably caused groundwater to migrate, which resulted in an increase in humidity and bearing capacity of the ground underneath the hangar. This seems to be confirmed by the increased flooding of the so-called manholes in the hangar, as well as by slight upthrusts of the slab along the gate.

The rosette located in the area of the load exerted by the wheels of the plane nose is positioned centrally in relation to the edges of the slabs that make up the main slab. Therefore, its exploitational strains are far smaller than in the case of other rosettes – all the more so that the

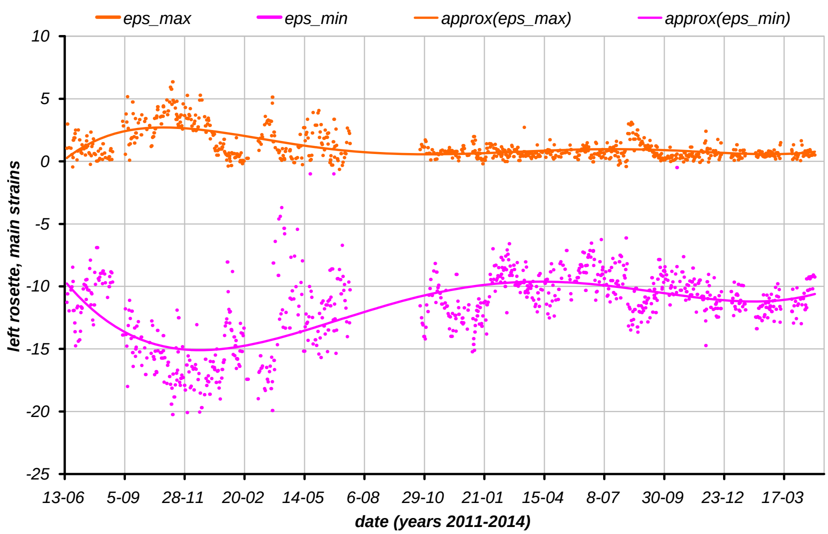

Fig. 11. The left rosette; a tendency towards change revealed by the values of the maximum *(eps. max)* and minimum *(eps. min.)* strains, for all the cases of stationing aircraft in the hangar

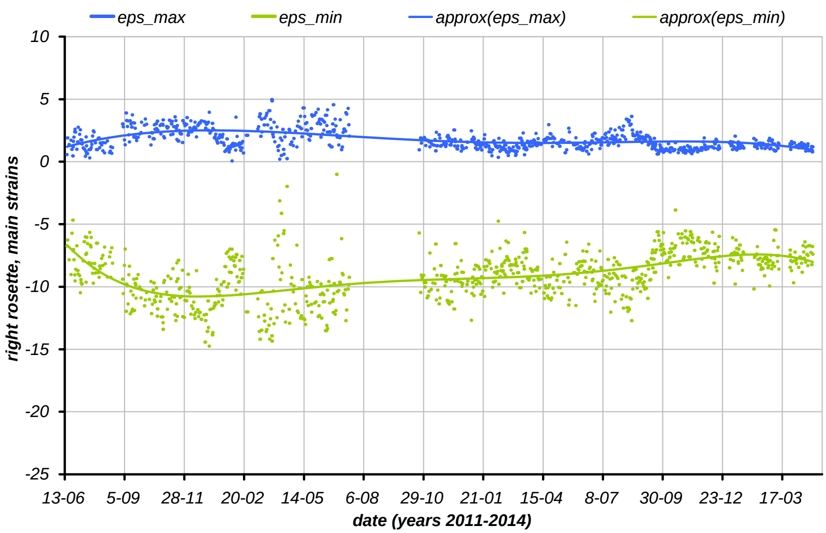

Fig. 12. The right rosette; a tendency towards change revealed by the values of the maximum *(eps. max)* and minimum *(eps. min.)* strains, for all the cases of stationing aircraft in the hangar

nose cone leg carries, at the most, 15% of the total aircraft weight. When analyzing total strains, one can see that the exploitational strains connected with the wheel load do not exceed several μm/m, and, as such, they cannot result in scratches. Thus, they are absolutely safe when it comes to the condition of the slab.

Due to the fact that each rosette is equipped with a thermistor, it is possible to estimate the thermal deformation of the slabs in the spots where the rosettes are located. Their values are included in the interval of 10÷14 μm/m, so they approximate the values of the concrete strains specified in mathemtical charts (*Tablice*..., 1995, p. 55). The hangar is heated in wintertime; in the summer, the temperature inside the hangar can even reach 30°C – as a result, a temperature gradient can be observed throughout the thickness of the slabs. This causes the slabs to curve, especially at the edges, which was demonstrated by relevant measurements (Kanciruk, 2012, p. 197). The aging of the slab material (i.e. the reinforced concrete) results in its slow contraction. After almost 3 years of observations (Fig. 13), the contraction reached the values from 120 μm/m (rosette *P*, minimum strain) to 230 μm/m (rosette *N*, maximum strain).

5. Summary

The vibrating wire measuring equipment, used in the measurements, proved highly reliable despite its prototypical character. It also revealed good metrological parameters, including high sensitivity. Due to over 50,000 strain measurements performed automatically (for each strain gauge), the main slab strains were registered for all the cases of stationing aircraft in the hangar that have taken place so far. It was also possible to register the slab strains caused by changes in the slab temperature and the aging of reinforced concrete. The monitoring of exploitational

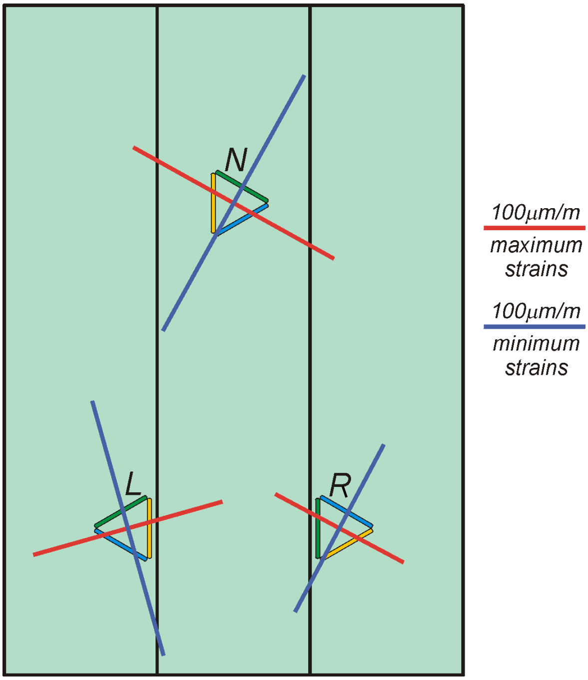

Fig. 13. The contraction of the slab material (reinforced concrete) in the spot where the measuring rosettes were located

strains proved that the slab strains occurring in the spot where the load from the wheels of the stationed aircraft is exerted might very well result in a damage to the structure of the concrete (the emergence of scratches) in the areas that are not available for direct observation.

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