Natural thermal loads and their influence on airfield concrete slabs

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Abstract. The article presents theoretical aspects of the influence of environmental changes on the extent of the recognized stress in the case of airfield concrete slab. Analyses included actual measurement data from 34 weather stations located within the area of Poland. The results obtained between 2000 and 2016 were used to prepare climatic data base of the selected regions. The analyses included maps of typical values taking into consideration daily, monthly and annual variations. In case of exemplary data from Kielce station, the influence of external conditions on the extent of the registered stress and deformations of airfield concrete slab was determined. According to the obtained test results, the significant influence of environmental conditions on changes of concrete slab strains was confirmed. Recommendations aiming at limiting negative influence of environmental conditions on concrete slab strains were suggested in case of the analysed area.

1. Introduction The essence of natural thermal stress in case of concrete pavement slabs

Pavements constructed using cement concrete method respond to variable weather conditions, which is strictly related to the properties of concrete composite. Concrete under the influence of temperature and humidity variations can change its volume, which consequently results in intensification of thermal stress [1-4]. Changes of dimensions and volume of concrete slabs are not visible in the course of actual pavement observations, however they result in slab effort and while exceeding limit values, may initially contribute to the occurrence of micro damages, and consequently cause more extensive damages. Temperature is a factor which influences concrete slab element [5], causing, among others, changes of linear dimensions. Temperature changes and, in particular, values around 0°C, are unfavourable factor in case of concrete slabs. Within the area of Poland, we can observe daily temperature variations, as well as annual temperature variations. It is determined, first of all, by solar radiation. It is estimated that approximately 57% of solar radiation reaches the earth surface and directly influences air temperature changes near the slab surface, as well as concrete slab temperature [3]. Cloudiness, which considerably diversifies influence of sun rays on the pavement, should also be considered while analysing climate impact. The area of Poland is clearly diversified in terms of climate. It is closely associated with weather fronts approaching Poland, that is humid air from the Atlantic Ocean and dry air from Europe and Asia. As a result, Poland has moderate transitional climate distinguished by eight seasons depending on daily temperature [6].
Air temperature is a factor which generates tensions of pavement slab, which is associated with the limited slab capacities of free volume change. At actual conditions, a pavement slab intended for use by aircraft is limited laterally by the neighbouring slabs and below by bottom construction layers and subgrade. Additionally, slabs are distinguished by diversified thermal parameters and variations may occur in case of individual sectors, due to variable environmental changes. In summertime, usually, the upper slab surface has higher temperature than the bottom part thereof and in winter time, the situation is just opposite, which, in case of limited slabs influences variable slab deformation, which was presented in Figure 1.

![Diagram presenting concrete slab deformation: a) in summer time and b) in winter time](image)

**Figure 1.** Diagram presenting concrete slab deformation: a) in summer time and b) in winter time

2. **The purpose and scope of the research**
Meteorological data provided by Institute of Meteorology and Water Management [7] was used for the purposes of this article. The subject of the analyses was data obtained during observations carried out between 2000 and 2016. The purpose of this publication was the analysis of meteorological data and taking into consideration the obtained parameters in case of concrete slabs dimensioning.

3. **Analysis of meteorological data**
Meteorological Climate-related data included the information concerning average daily temperature, hourly air temperature, minimum temperature near the ground surface, sunshine duration and cloudiness. According to data collected from 34 measuring stations located across the entire country (Figure 2), climatic data base was prepared for the purposes of numerical analysis of airfield concrete slabs.

![Location of all meteorological stations included in the analysis](image)

**Figure 2.** Location of all meteorological stations included in the analysis
According to the analysis of the obtained results, average daily temperatures in case of each analyzed station were determined. Results obtained during the entire analyzed period, i.e. from 01.01.2000 until 31.12.2016 were taken into consideration with reference to average daily temperatures. Table 1 includes general list of values typical for each station.

Table 1. Average determined daily air temperatures.

| Meteorological station | Average daily temperature [°C] | Temperature dispersion [°C] | Meteorological station | Average daily temperature [°C] | Temperature dispersion [°C] |
|------------------------|--------------------------------|-----------------------------|------------------------|--------------------------------|-----------------------------|
| Białystok              | 7.7                            | 8.7                         | Nowy Sącz              | 9.1                            | 8.4                         |
| Bielsko-Biała          | 9.1                            | 8.3                         | Olsztyn                | 8.1                            | 8.4                         |
| Chojnice               | 8.2                            | 8.0                         | Opole                  | 9.7                            | 8.3                         |
| Gdańsk                 | 9.0                            | 7.5                         | Ostrołęka              | 8.3                            | 8.7                         |
| Gorzów Wlkp.           | 9.5                            | 8.0                         | Poznań                 | 9.5                            | 8.3                         |
| Jelenia Góra           | 8.1                            | 7.9                         | Rzeszów                | 9.0                            | 8.7                         |
| Kalisz                 | 9.4                            | 8.4                         | Suwałki                | 7.3                            | 8.3                         |
| Katowice               | 9.1                            | 8.3                         | Szczecin               | 9.6                            | 7.5                         |
| Kielce                 | 8.4                            | 8.6                         | Świnoujście             | 9.2                            | 7.2                         |
| Koszalin               | 8.9                            | 7.4                         | Terespol               | 8.5                            | 8.8                         |
| Kraków                 | 9.0                            | 8.5                         | Toruń                  | 9.0                            | 8.4                         |
| Lesko                  | 8.3                            | 8.3                         | Ustka                  | 8.9                            | 7.1                         |
| Lublin                 | 8.4                            | 8.8                         | Warszawa               | 9.1                            | 8.7                         |
| Leba                   | 8.6                            | 7.1                         | Wrocław                | 9.8                            | 8.1                         |
| Łódź                   | 8.9                            | 8.5                         | Zakopane               | 6.3                            | 8.2                         |
| Mikołajki              | 8.1                            | 8.6                         | Zamość                  | 8.5                            | 8.1                         |
| Mława                  | 8.3                            | 8.6                         | Zielona Góra           | 9.5                            | 8.2                         |

According to the obtained results, in case of average daily temperature criterion, it was claimed that the warmest towns are Wrocław (T_d=9.8°C) and Opole (T_d=9.7°C). While Zakopane (T_d=6.3°C), Suwałki (T_d=7.3°C) and Białystok (T_d=7.7°C) have the lowest average daily temperature. It should be noted that average daily temperature variations within the area of the entire country are similar and range between 7,1°C and 8,8°C. For the purposes of better visualization of a certain parameter, maps of Poland, including the range of the occurrence of a given temperature, were prepared - Figure 3. Based on the analysis of the obtained results, it was claimed that clearly higher average daily temperatures occur in western, south-western and central part of Poland. While regions of northern, north-eastern and southern Poland are the areas where lower average daily temperatures occur.
Figure 3. Diversification of average daily air temperature between 2000 and 2016 in case of the analyzed measurement stations

With reference to concrete pavement slab operation, first of all, the information about changes of daily temperature is significant. Intuitively, it is known that the temperature will be higher in the afternoon and lower at night. Table 2 presents values of average air temperatures at certain measurement hours determined in case of all analyzed meteorological stations.

| Time   | Average daily temperature [°C] | Temperature dispersion [°C] | Time   | Average daily temperature [°C] | Temperature dispersion [°C] |
|--------|-------------------------------|-----------------------------|--------|-------------------------------|-----------------------------|
| 00:00  | 6.6                           | 7.5                         | 12:00  | 11.7                          | 9.5                         |
| 01:00  | 6.3                           | 7.4                         | 13:00  | 11.9                          | 9.6                         |
| 02:00  | 6.1                           | 7.3                         | 14:00  | 11.8                          | 9.6                         |
| 03:00  | 5.9                           | 7.3                         | 15:00  | 11.5                          | 9.7                         |
| 04:00  | 6.0                           | 7.4                         | 16:00  | 10.9                          | 9.6                         |
| 05:00  | 6.4                           | 7.9                         | 17:00  | 10.3                          | 9.4                         |
| 06:00  | 7.2                           | 8.5                         | 18:00  | 9.5                           | 9.0                         |
| 07:00  | 8.1                           | 9.0                         | 19:00  | 8.7                           | 8.4                         |
| 08:00  | 9.1                           | 9.2                         | 20:00  | 8.1                           | 8.0                         |
| 09:00  | 10.1                          | 9.3                         | 21:00  | 7.6                           | 7.9                         |
| 10:00  | 10.8                          | 9.4                         | 22:00  | 7.2                           | 7.7                         |
| 11:00  | 11.4                          | 9.4                         | 23:00  | 6.9                           | 7.6                         |

Figure 4 presents detailed courses of temperature changes during daily cycle in case of selected 7 stations.
Figure 4. Distribution of air temperature during 24 hours in case of selected measurement stations

According to the analysis of the obtained results it was claimed that two extreme situations occur during 24 hour. The lowest temperatures within 24 hours were registered at night between 02:00 and 04:00. And they are from 3.5°C to 7.5°C accordingly (at 02:00), from 3.3°C to 7.4°C (at 03:00) and from 3.4°C to 7.4°C (at 04:00). While the highest temperatures within 24 hours were registered between 12:00 and 14:00. And they are from 9.7°C to 13.1°C accordingly (at 12:00), from 9.8°C to 13.4°C (at 13:00) and from 9.5°C to 13.3°C (at 14:00).

Apart from daily air temperature changes, in terms of concrete pavement operation, annual cycles changes are also significant. It is obviously determined by geographic location of our country and the Earth’s orbit. Therefore, average air temperatures in case of all measurement stations in particular months were determined.

The lowest average temperatures were determined in January (-1.6 °C) and February (-0.5 °C), and the highest in July (19.0 °C) and August (18.3 °C). Figure 5 presents average air temperatures changes in particular months in case of 7 selected meteorological stations.

Figure 5. Average monthly air temperatures in case of the selected measurement stations
It was determined that temperatures distribution in summertime is of parallel-oriented nature while in wintertime of longitudinal nature, which can be observed in the attached maps - Figure 6, 7. In July, average air temperatures in central part of Poland are above 19°C (Warszawa 20,1°C, Poznań 19,9°C), while northern regions (Ustka 18,1°C) and southern regions (Zakopane 16°C) of our country have lower average temperatures. In January, in eastern parts of Poland (Suwałki -3,9°C, Rzeszów -2,0°C), temperature drops below zero, while in western parts of the country the average temperature is around 0°C (Szczecin 0,3°C, Wrocław -0,3°C).

![Figure 6. Average air temperatures between 2000 and 2016 in case of the analyzed measurement stations: a) in July, b) in January](image)

Low temperatures are particularly dangerous in case of concrete pavements because they have destructive influence not only on the pavement surface itself but also on lower structural layers. Water which occurs on the pavement penetrates the cracks and when it began to freeze its volume increases when the temperature decreases. Consequently, micro cracks can appear, which, due to the recurring adverse environmental conditions may extend their range and influence reduction of pavement durability.

![Figure 7. Temperature diversification at ground level](image)
Huge ambient temperature variations cause alternating increase and decrease of linear dimensions of concrete composite. Therefore, the number of temperature changes from plus to minus, i.e. getting past 0°C is also significant. Figure 8 presents detailed diagram of registered air temperatures every one hour in case of a selected measurement station Kielce-Suków in exemplary 2016. According to the obtained results it was claimed that in case of this station, within one year, 147 temperature changes from minus to plus or opposite were registered. The number of these changes was diversified in particular months and it amounted to: in December - 34, in March - 28, February - 23, January - 22, November - 19, April - 9, May - 6 and October - 6.

**Figure 8.** Diversification of air temperature registered by meteorological station Kielce-Suków from 01.01.2016 until 31.12.2016

It is assumed that the distribution of phenomena occurring in the nature is similar to normal distribution. Normal distribution for the determined average annual air temperatures registered by Kielce-Suków station between 2000-2016 was specified (Figure 9). The analysis included the application of Shapiro-Wilk and Kolmogorow-Smirnow tests. According to the obtained test probabilities where the values were higher than the assumed statistical significance level, (p>0,05) the nature of distribution was determined normal.

**Figure 9.** Indication of distribution of the registered average daily temperatures in case of meteorological station Kielce-Suków between 2000-2016
4. The influence of actual meteorological information on the extent of concrete slab effort
The subject of the research paper included free concrete slab of the following dimensions: 5x5 m. The assumed thickness of the slab was 30 cm, it was made of C25/30 class concrete, the flexural module of which equalled to $E=31000$ MPa, Poisson coefficient was $\nu=0.2$, thermal expansion coefficient of concrete $10^{-5}$ 1/o$^\circ$C, and specific weight of concrete $\gamma=24.53$ kN/m$^3$. Initially, it was assumed that the concrete slab is located on resilient subgrade with the elasticity coefficient of $K_z=50000$ kN/m.

The analysis included the reference slab—without thermal load and the slab with thermal in the form of gradients assumed according to minimum temperatures near the ground in case of the measurement station Kielce-Suków on a monthly basis (table 3).

**Table 3.** The list of results obtained in case of the reference slab and a concrete slab of temperature gradient

| month     | temperature gradient (+) positive | maximum displacement [mm] | maximum stress [MPa] | month     | temperature gradient (-) negative | maximum displacement [mm] | maximum stress [MPa] |
|-----------|-----------------------------------|---------------------------|----------------------|-----------|-----------------------------------|---------------------------|----------------------|
| Styczeń   | (-) 7.9                           | 0.953                     | 0.36                 | Lipiec    | (+) 12.5                          | 2.084                     | 0.64                 |
| Luty      | (-) 0.9                           | 0.106                     | 0.06                 | Sierpień  | (+) 10.5                          | 1.751                     | 0.50                 |
| Marzec    | (-) 0.8                           | 0.095                     | 0.05                 | Wrzesień  | (+) 7.8                           | 1.300                     | 0.37                 |
| Kwiecień  | (+) 2.5                           | 0.417                     | 0.15                 | Październik | (+) 3.7                           | 0.617                     | 0.17                 |
| Maj       | (+) 6.6                           | 1.101                     | 0.31                 | Listopad  | (-) 1.0                           | 0.118                     | 0.08                 |
| Czerwiec  | (+) 10.5                          | 1.751                     | 0.50                 | Grudzień  | (-) 3.5                           | 0.414                     | 0.12                 |

According to the obtained test results it was proved that in thermal respect, the most unfavourable conditions in case of concrete slab will occur in March and July, therefore further analyses referred to these months. Figures 10 and 11 present the obtained maps presenting stress and displacement in case of the designed slab taking into consideration the actual thermal conditions.

**Figure 10.** A map presenting the determined stress in the analyzed concrete slab taking into consideration the actual thermal loads: a) in March, b) in July
Figure 11. Map presenting displacements in the analyzed concrete slab: a) in March, b) in July

5. Conclusions
According to the analysis of the results obtained from 34 measurement stations located within the area of the entire country the following was proved:

1) in case of the assumed analysis period (between 2000-2016) and the criterion regarding hourly temperature change on daily basis, there are two extreme situations. The lowest temperatures (at night time, between 02:00 and 04:00).

2) in case of the criterion regarding average daily temperature, the warmest towns are Wrocław (T_d=9.8°C) and Opole (T_d=9.7°C), and the coldest towns are Zakopane (T_d=6.3°C) and Suwałki (T_d=7.3°C). Variations of average daily temperatures range between 7.1°C and 8.8°C.

3) in case of the criterion regarding average annual temperature change, the lowest average temperatures occur in January (-1.6 °C) and February (-0.5 °C), and the highest temperatures occur in July (19.0 °C) and August (18.3 °C).

4) in case of the selected Kielce station in 2016, 147 temperature changes ranging around 0°C, i.e. changing from plus to minus and opposite were registered, with the prevailing number occurring in December and March.

5) in case of the designed concrete slab (30 cm thick made of concrete of C25/30 class) the influence of actual conditions on the extent of slab effort was determined. Increase of 38% in case of stress was proved and increase by 18% in case of the registered deformations of a concrete slab exposed to the influence of thermal loads in terms of reference slab.

The obtained test results lead to the conclusion that the thorough analysis of climatic phenomena within the area of Poland is necessary and crucial for the proper designing, constructing and maintenance of pavements made of cement concrete.

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