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THE USE AND EFFECTIVENESS OF HIGHWAY LANDING STRIP CONSTRUCTION IN POLAND

Summary. The efficiency of maintaining road pavements in good condition in Poland, and, in particular, maintaining their good technical condition, depends mainly on the availability of financial resources and conducting ongoing works related to road operation and maintenance. Selected European countries, including Poland, reactivated the concept of reconstruction and use of highway landing strips. Based on the analysis of the technical parameters of a newly built highway landing strip, this publication presents, using the finite element method (FEM), the verification of the technical parameter values potentially resulting from the maximum load caused by a C-130 Hercules aircraft.

Keywords: highway landing strip, finite element method, road infrastructure, financial resources

1. INTRODUCTION

Transport is an activity involving the proper movement of people and cargo in space from the point of posting to the point of reception using the appropriate means of transport, as well as the provision of related auxiliary services, such as forwarding. Execution of this task requires performing a number of activities and creating the appropriate conditions in order to make this process effective in the context of three fundamental elements: safety, time, and costs. Transport is a branch of the national economy that is very closely connected with

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the national budget, and the strength of this relationship is evidenced by the amount of state budget funds spent on investment, modernisation, operation, and maintenance of transport infrastructure. Transport services, particularly road transport services, are one of the factors which stimulate the economic development of Poland.

The development of road infrastructure is often used as a kind of instrument in the political game. Assumptions, plans, and prospects for the construction of new elements of the so-called road network infrastructure are frequently treated as some sort of arguments and bargaining cards. Without any doubt, it is the road infrastructure which directly influences the economic development of our country and its individual regions and is the key to its rational and sustainable development. Wrongly developed strategic plans result in poor operational decisions, which in combination with enormous financial outlays cause in such a case a huge disappointment if not the frustration of the society. Therefore, in order to properly serve its users, transport infrastructure together with other facilities requires appropriate and rational planning, as well as operational and maintenance works. Technical condition of the roads, as well as the comfort and duration of the transport process, depend directly on the effective execution of these works. The condition of roads, on the other hand, indirectly influences the mobility of society, the development of the national economy, as well as the spatial cohesion of the country [1,6,9]. This is the reason it is so important to adopt specific strategic objectives and allocate funds to meet them in terms of optimising efficiency throughout the life cycle of the product being the process of preparation for the investment project, its implementation, construction, and the actual use. [12,5]

In Poland, the state is responsible for maintaining national roads and it delegates this power to the administrator, that is, the General Director of National Roads and Motorways and the road authority acting on his behalf – the General Directorate for National Roads and Motorways (in Polish, GDDKiA). Objective and appropriate assessment of GDDKiA's activity is a broad issue and it requires the use of a specially developed set of indicators for measuring the effectiveness of road maintenance management. Data concerning the technical condition of the road pavement, together with information on vehicle traffic, and the traffic accident analysis, are important elements used in the road management process. Every year, in the first quarter, GDDKiA publishes its report on the technical condition of the pavement of the national road network for the preceding year. On the basis of the data in question, GDDKiA develops, among others, the measures for the *Annual Operating Plan of the General Directorate of National Roads and Motorways* and the measures for the financial plan in the classification system of the activity-based budget. Investments concerning national roads are currently conducted in accordance with the national road construction program for the years 2014-2023 (with a perspective until 2025), which was approved on 8th September 2015 by the resolution of the Council of Ministers (that is, the Polish Government). This program sets out the directions of activities and investment priorities within the development framework of the Polish national road network. Furthermore, it diagnoses the current road sector condition and defines both the objectives planned for implementation and also the key areas constituting the so-called bottlenecks. Additionally, It makes reference to the commitments and challenges that Poland may be facing in the near future.

The analysis of annual reports in view of its comparative assessment shows that in recent years, GDDKiA has made significant progress, among other things, in the development of standards for the ongoing road maintenance and the pavement condition assessment. Owing to the adoption and implementation of best international practices, the operational efficiency of the road administration in Poland increased slowly and successively. At the end of 2017, according to the GDDKiA report, the global assessment of the network of national roads, taking into account their pavement condition, was as follows:

- desirable/good condition – 58.1% (12,342 km),
- unsatisfactory/warning condition – 27% (5,534 km),
- critical/inadequate condition – 14.5% (3,077 km).

In comparison with the analogous report on the pavement condition from 2007, there was an almost 8% decrease in the length of the road network in Poland, whose condition was described as critical, and an increase in the percentage of pavements described as unsatisfactory (4.5%) and desirable (3%) [4].

National road construction program for the years 2014-2023 (with a perspective until 2025) is the document which defines road infrastructure development goals, includes a schedule of investment implementation to achieve them, and indicates the financing sources with the amount of planned outlays. The main goal of the program is to build a modern and coherent national road network that would ensure the effective functioning of passenger and freight road transport. It is planned that after the implementation of the program, in 2023, GDDKiA will manage a total of over 22 thousand kilometres of roads, over 4,600 km of which will be highways and expressways. The total length of the national network will include 20,660 km of asphalt roads (approximately 94%) and 1,350 km of concrete roads (over 6%) [10].

2. HIGHWAY LANDING STRIP

Even though road infrastructure is mainly used to provide transport with wheeled motor vehicles, in recent years, separate fragments of road pavements have been used with varying intensity as elements of airport infrastructure. The origin of road runways, called highway landing strips, dates back to World War II when military decision-makers noticed for the first time the possibility of using an extensive system of highways as potential temporary airports. A widespread and relatively modern network of highways having a length of approximately 14,000 km was a perfect base for that. Until the outbreak of World War II, the Germans managed to build almost 52 million square meters of roads with concrete pavement, approximately 80% of which were concrete-paved highways. In the course of the war, intense air raids on airport infrastructure somehow forced the necessity for alternative ways to ensure the possibility of conducting air operations by own forces. The end of World War II was a period of time during which in various European countries, including Poland, became very popular to create visions of air force functioning based on the use of highway landing strips. Most of the highway landing strips were situated in the western and northern parts of the country, which resulted from the geopolitical situation and potential threats from enemy air force during the Cold War era.

The end of the Cold War period caused a change in defence policy based on the alternative use of temporary airport infrastructure in most European countries. Similarly in Poland, there was a lack of interest in the concept of further use and maintenance of the existing highway landing strips and the plans for the construction of new ones.

3. REACTIVATION OF THE CONCEPT OF BUILDING HIGHWAY LANDING STRIPS IN POLAND

The breakthrough event for the reactivation of the concept of building highway landing strips in Poland was 7 May 2013, when the contract was signed for the continuation of the A4 highway construction, from the Krzyż interchange to the Dębica Pustynia interchange. The general executor of the investment project was Heilit-Woerner Sp. z o.o. consortium and Budimex S.A company. The total value of the contract was 981.5 million PLN. After many years, the first completely new highway landing strip was built on the newly built section of the A4 highway between Tarnów and Dębica. Plans to create a highway landing strip at the same place commenced in 1998 when the location for the facility was pointed out by the Ministry of National Defence. The characteristic features of the highway landing strip in Jastrząbka are: length 3 km, width 30 m, 15 m shoulders free from obstacles, and mobile concrete barriers, easy to be deployed quickly if necessary (Fig.1). At the beginning and end of the highway landing strip, there are widened areas, the aprons for parking aircraft, where aircraft maintenance may be conducted (refuelling, inspections, munitions resupply).

The history of recent wars shows that one of the most effective combat tactics used by the air force in the battle for air superiority is a preemptive strike on the enemy's air force. Disabling the air force and preventing its operation for a period of several days is of decisive importance, particularly in the initial phase of an armed conflict. It is anticipated that operationally sensitive elements of airfields will be attacked to prevent their use in order to paralyse the air force.

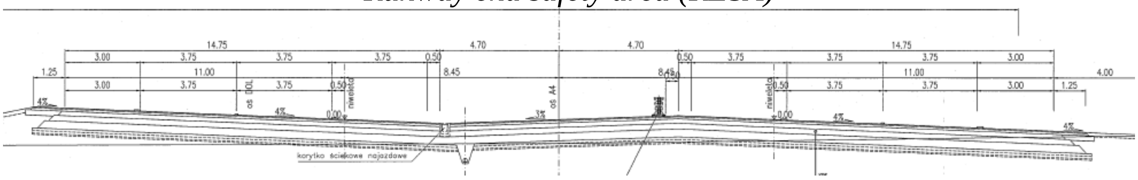
Airfields to be attacked in the first place will be home airbases, then the remaining regular airbases (alternate), and finally, highway landing strips. The most important elements that determine the operation of any airport include manoeuvring areas and main taxiways. Therefore, their pavement constitutes primary targets of the enemy's destructive actions.

Will the change in the planning policy and, in consequence, also the organisation of a "new" type of road infrastructure in Poland have a long term influence on its use? Will the reactivation of the highway landing strip construction in Poland lead to the creation of a concept for their use by the military and civil aviation? Will this type of airport infrastructure elements work well in potential future conflicts, using advanced modern munitions, as well as aircraft which will require an infrastructure of the appropriate "quality".

In the 1990s, Poland officially had 21 highway landing strips. The analysis of their present technical condition points out to the fact that currently only one of them in the vicinity of the city of Szczecin is active. There are two main reasons that have led to their current state: repairs and modernisations for many years were not taken into consideration, leaving the road infrastructure, its landing strip function, and the gradual deterioration of the technical condition of the remaining highway landing strips in bad states, automatically eliminating their potentials as possible airfields.

The analysis of the documentation of the newly created highway landing strip, going back to the concept from the turn of the century, and the lack of precise plans for the construction of new strips, prove that there is a lot of tardiness or even a lack of interest in reactivating them. The main problem area to be assessed is the analysis of traffic organisation in the event of a temporary closure of the road on which a highway landing strip is located. Moreover, following the example of the Scandinavian countries, training should be regularly conducted on such installations in order to maintain high combat readiness. Conducting such training with the aircraft currently operated by the Air Force (F-16) is unlikely due to their susceptibility to FOD (*Foreign Object Damage*). Given the restrictive standards concerning, among other things, cleanliness, preparing a landing strip on an ordinary national road may prove difficult.

Cross-section on the highway landing strip
Runway end safety area (RESA)



Cross-section on the highway landing strip
Runway section

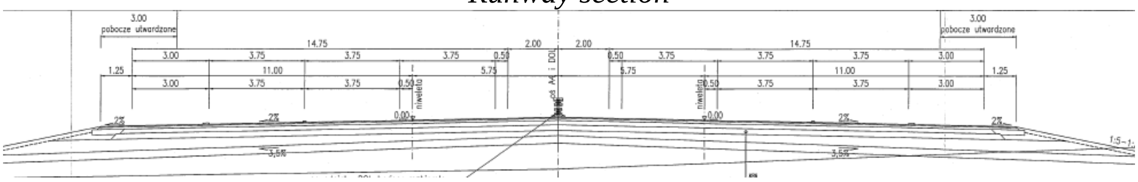


Fig.1 The cross-section of the highway landing strip in Jastrząbka
Source: on the basis of the materials by Budimex SA, ul. Stawki 40, 01-040 Warszawa, from 15th October, 2018

Airport pavements have undergone tremendous technological evolution compared to their original models from the early 1920s. Airport pavements may be divided into two basic groups:

- *natural pavements*, which includes dirt, grass and turf surfaces,
- *artificial pavements*, which regarding the manner of load transfer are divided into:
  - rigid pavements made of cement concrete,
  - flexible pavements made on the basis of bituminous binders,
  - mixed construction pavements.

Currently, concrete pavements are increasingly used in the construction of airports, and building of the national road network.

Advantages of concrete pavements in the context of highway landing strip construction:

- high durability independent of the season, and variable load carrying capacity of the subgrade,
- low rolling friction coefficient,
- high sliding friction coefficient,
- good resistance to high temperatures caused by exhaust gases of aircraft engines,
- good resistance to greases and fuels used in aviation,
- bright colour increasing visibility and contrasting well with the surrounding pavement of the shoulders.

Disadvantages of concrete pavements:

- low use of the permissible compressive stress of concrete,
- large length of expansion gaps being the weakest places of concrete pavements
  - slightly higher construction costs [4, 6].

Analyses of highway landing strips in use mainly in Europe show that most of them are made in concrete technology. Was the idea of their construction using bituminous technology, whose main disadvantage is much lower strength, and, what it involves, durability, justified? In the case of highway landing strips, however, their durability will be determined mainly by the effects of wheeled vehicle traffic. One of the extremely important reasons for the gradual decline in the road quality is the fact that carriers do not comply with the maximum authorised payload and permissible axle loads, despite the fact that the law precisely determines the values of those parameters.

The Regulation of the Minister of Infrastructure of 31 December 2002 on the technical conditions of vehicles and the extent of their obligatory equipment in conjunction with the changes introduced by the Regulation of the Minister of Infrastructure and Development of December 30 2013 precisely define the permissible axle load value and the maximum authorised payload of a truck, depending on axle configuration, and in the Regulation of the Minister of Transport and Maritime Economy of March 2 1999 regarding road classes (7 classes – denoted as A, S, GP, G, Z, L, D). In Poland, allowable static axle loads of 80, 100, or 115 kN are accepted depending on the public road category. In reality, given vehicular traffic, dynamic loads exerted on pavements is much greater than static, and the impact of heavy vehicles on road pavement is more aggressive than previously assumed [15].

Despite the regulations in effect, a significant proportion of heavy goods vehicles do not comply with the rigours of allowable axle loads. Overloaded trucks cause great losses for the economy of Poland. According to GDDKiA, approximately 30% of heavy goods vehicles on Polish roads are overloaded, which results in losses in road infrastructure ranging from PLN 6 to 8 billion annually (this cost is comparable to the cost of construction of approximately 300 kilometres of an expressway).

Standard technical indicators of road infrastructure maintenance refer mainly to the description of the technical parameters of the pavement and subgrade [7,8,13]. Technical efficiency and effectiveness of road maintenance (including highway landing strips) are described by such indicators as:

- roughness of the pavement and its anti-skid properties (the main factor influencing traffic safety),
- longitudinal and transverse evenness of the road (a parameter affecting driving comfort and safety),
- wheel load capacity of the road - a parameter ensuring the durability of individual road layers during the assumed period of pavement use. The factor inseparably related to the pavement thickness and its material parameters.

3. EFFECTIVENESS OF HIGHWAY LANDING STRIP CONSTRUCTION

One of the non-invasive methods of learning about the nature of the impact of operational loads caused by aircraft on airport pavements is the strength analysis of the surface using the finite element method (FEM). The main objective of this study is to present general assumptions and possibilities of the practical application of a numerical method for assessing the strength of concrete airport pavements used for the construction of highway landing strips. An alternative verification of the surface in relation to empirical methods was presented on the basis of the developed universal calculation algorithm based on FEM [2].

In this presented work, calculations were made for the C-130 Hercules aircraft (Fig. 2a) being potentially the largest military transport aircraft that can perform air operations on highway landing strips.

The basic strength condition in cement concrete pavement design, using the Westergaard method, is the comparison of the stresses occurring within the slab in its centre, at the edge, and in the corner with the permissible stress values.

$$\sigma_{S,K,N} \le \sigma_{dop} \tag{1}$$

Operational loads in the numerical model were described assuming that the surface is statically loaded with the maximum take-off weight exerted by a Hercules C-130 military aircraft, by assigning specific values of pressure applied to the upper layers of the slab in the locations resulting from the geometry of the aircraft landing gear footprint (Fig.2b). The principle of selecting wheel tracks assumed was based on the finite element mesh. In the finite element method, in the case of a 2D slab model, we obtained the components of a flat state of stress on the upper and lower surface of the slab, whereas in the case of a 3D model, we obtained the components of the spatial stress state in the entire slab.

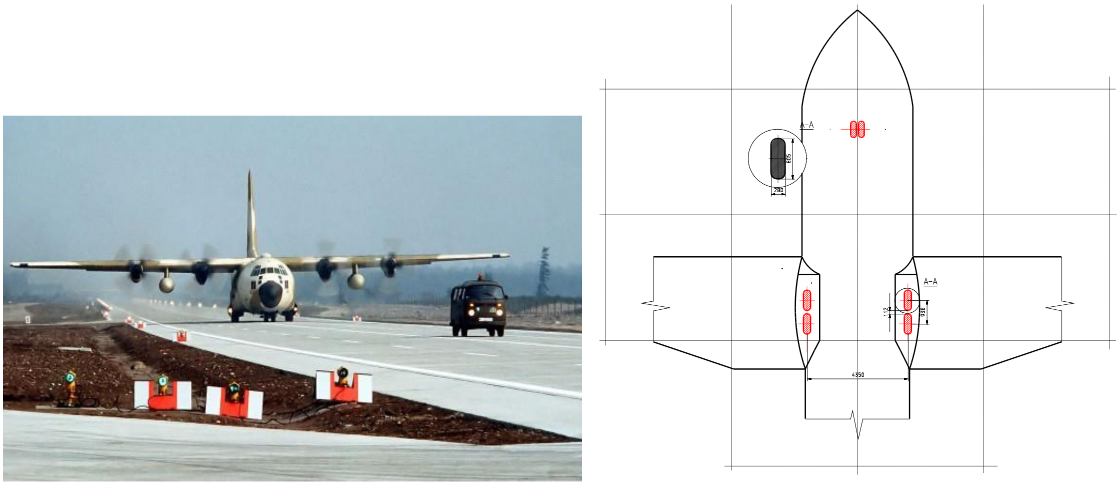


Fig. 2. Hercules C-130 aircraft landing on a highway landing strip (a), geometry of Hercules C-130 wheel tracks (b)

In the analyses, the following values were assumed:

- slab dimensions *5x5* m,
- concrete slab thickness $h=0,30$ m,
- modulus of concrete elasticity $E=32$ GPa,
- poisson's ratio $v = 0,17$.

Basic aircraft data necessary for conducting the analysis:

- take-off weight $M_{min/max}=79380/120000$ kg,
- maximum take-off weight $G_c=120 \cdot 10^4$ N,
- weight on main lading gear strut:

$$P_k = 0{,}8\frac{G_c}{2} = 480\ \ kN \tag{2}$$

Own weight of the slab and thermal loads were excluded from the analysis.

The aircraft has a tricycle landing gear with dual nose gear wheels (Fig. 2). The construction and tires allow the operation of the aircraft from unpaved airstrips. Main landing gear wheels with 1005 x 280 tires and 0.72 MPa pressure. Nose gear wheel with 380 x 150 tires and 0.54 MPa pressure. A substitute area of pressure exerted by one wheel of the aircraft was adopted for analysis: F_z=2400 cm^2, which corresponds to the area of a rectangle formed with 24 elements of the slab. For the tandem-type main landing struts, that corresponds to 48 elements of the slab.

The analysis was performed for three load variants:

- VARIANT I – the slab was loaded in the centre with one main landing gear strut (two-wheeled, tandem),
- VARIANT II – the slab was loaded at the edge with two main landing gear struts,
- VARIANT II – the slab was loaded in the corner with two main landing gear struts.

Taking into consideration its dimension relations (500:30), the slab analysed should be included in the medium thickness class. In order to determine displacements and stresses in concrete airport pavements under static loads with the selected aircraft type, the MSC.NASTRAN for WINDOWS system was used [3].

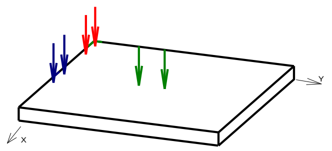
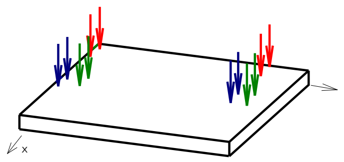
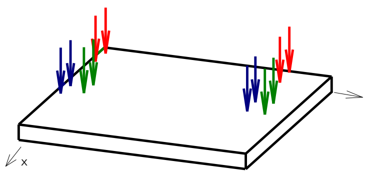
The model used 7,500 eight-node solid elements of 0,1 x 0,1 x 0,1 [m] each, and 2601 elastic GAP type elements. Sample calculations were performed for the three load variants described above, for both airport ramp models. The results of slab deflections were fully consistent both for the 2D and 3D models. The maximum deflection values calculated for the 3D model for all load variants are shown in Table 1. As can be observed there, the value of the maximum slab deflection depends strongly on the location where the load is exerted and varies from 0.99 mm for the strut in the centre of the slab to 3.34 mm for the load in the corner. Selected distributions of deflection values are presented as contour plans (Fig. 3). By analysing the contour plans of the deflections, it can be noticed that in particular load variants, certain slab areas break away from the subgrade (the displacement values are positive, marked by the red colour of the contours). In the first load variant, the corners of the slab rise (Fig. 3/1 and Fig. 3/2), in the second variant – the slab areas adjacent to the edges perpendicular to the loaded edge rise (Fig. 3/3); in the third variant with the maximum deflection, the right-hand side half of the plate loses contact with the subgrade (Fig. 3/4), the zero contour line runs approximately through the centre of the green field on a contour plan.

As a result of the static analysis, FEM gives a complete set of information about the state of displacements and stresses within the model. Considering the specific properties of the material from which the airport pavement slab should be made – very high compressive strength and about ten times lower tensile strength, a hypothesis of the maximum tensile stress was assumed as the strength criterion. Distributions of the maximum principal stress on the upper or lower surface of the slab for selected load examples are presented in the contour plans shown in the illustrations (Fig. 3/5-8). When comparing the values obtained for both models (2D, 3D), a very low discrepancy can be found – the differences do not exceed two per cent. It should be noted, however, that the allowable stress values do not exceed the stresses for the assumed brand of concrete [3].

In Table 1, the maximum deflections and the maximum principal stress values of the slab calculated for the doweled slab model for all load variants are given for comparison with the undoweled slab. As observed, the value of the maximum deflection of the doweled plate, similar to that for a slab without dowels, depends on the load application location, but the deflection value for the corner and edge variant (about three times smaller) has decreased significantly. It is worth noting in the case of doweling that the stress values have decreased considerably and, as opposed to the undoweled slab, they show smaller discrepancies of the results.

Tab. 1

List of maximum deflections and maximum principal stresses for the Hercules C-130 aircraft

Model	*VARIANT*	*Location of slab load*	σ_{max} *max. principal stress MPa*	*z max. deflection mm*
Hercules C-130 – undoweled slab				
	VARIANT I	CENTRE	***4.37***	***0.99***
	VARIANT II	EDGE	***5.64***	***2.76***
	VARIANT III	CENTRE	***6.62***	***3.34***
	VARIANT I	CENTRE	***4.37***	***0.99***
	VARIANT II	EDGE	***5.77***	***3.01***
	VARIANT III	CORNER	***6.65***	***5.70***
Hercules C-130 – doweled slab				
	VARIANT I	CENTRE	**3.23**	**1.06**
	VARIANT II	EDGE	**3.36**	**1.27**
	VARIANT III	CORNER	**3.79**	**1.78**

A sample analysis of a single airport slab with free, undoweled, edges without considering their mutual cooperation showed the necessity of doweling the pavement. As part of follow-up activities, more works and theoretical research on increasing the efficiency of technologies for the construction of future highway landing strips should be conducted.

4. CONCLUSIONS

Presently, highway landing strips are characterised by a different specificity and they undoubtedly combine to a certain extent functions related to air and road transport. They are still separate, straight, and long road sections, which from the drivers' perspective, are sometimes hard to notice, as what distinguishes a given road section as a highway landing strip is below the roadway level. The pavement construction of contemporary highway landing strips is completely different from typical roads. Potential loads from military aircraft force strengthen the properties of the pavement making it better.

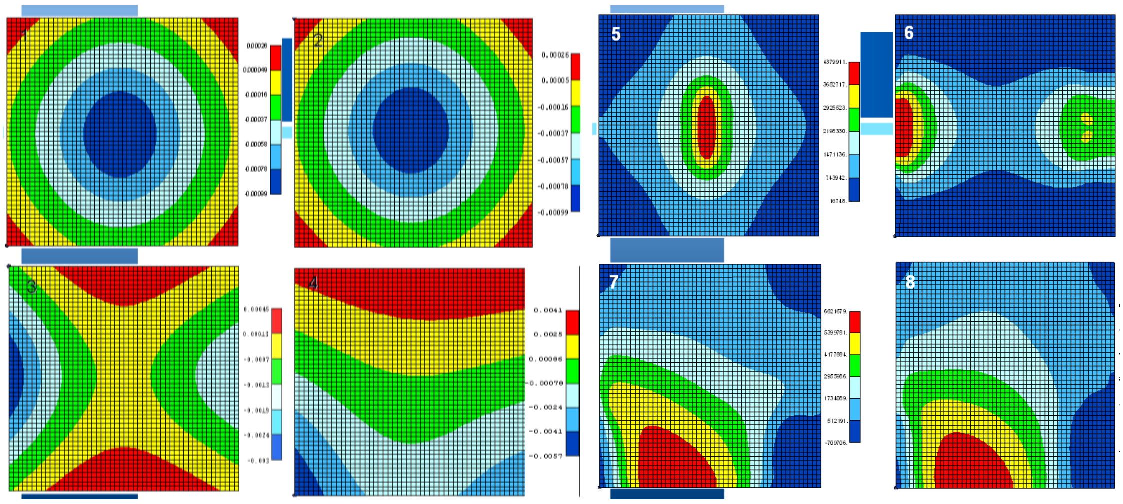


Fig. 3. Slab deflection distribution (items 1÷4) m and the distribution of maximum principal stresses within the slab 5÷8 (items 5÷8) Pa

Since 28th May 2003 when two MiG-21 aircraft landed on the Kliniska highway landing strip, no exercise at highway landing strips has been conducted in Poland. There is still no reason for announcing the reactivation of the concept of using this type of infrastructure, despite the fact that a completely new highway landing strip, situated on the A4 highway between Tarnów and Dębica has been commissioned. It is hard to find investment plans for the construction of further highway landing strips, which in the event of a war or crisis situation could be used as temporary field aerodromes. Strategic significance and the role of highway landing strips in potential conflicts may, however, be classified as secret. However, analyses of very faint possibilities of concealing this type of characteristic elements of road infrastructure in the 21st century point out to the fact that the possibilities of using highway landing strips in Poland are very limited. The second factor to take into consideration when selecting a location for the planned new highway landing strip is the increase of their efficiency and duration of use by applying technology based on rigid pavements. Full analysis of the results and comparing them in the context of other concrete surfaces, including non-reinforced pavements and doweled pavements in connection with the introduction of ever higher operational loads and increasing traffic, confirms the need to use new, more durable and safe, pavements, and, involving the use of modern calculation methods to determine their optimum design.

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