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DOI: 10.35117/A_ENG_18_11_05

Individual approach to road surfaces in design and build delivery system

Abstract: At the end of 2017 in Zachodniopomorskie voivodeship there were 14 ongoing projects on the A6 highway and other expressways. The total length of construction was 222 km with overall investment value of over 5 billion Polish Złoty. The majority of the projects are delivered in the design and build approach. The longest section (117,8 km) constructed under D&B approach is located on the S6 expressway between Goleniów and Koszalin. The investment was divided on 6 separate sections. The contractors tried to optimize the design solution during the preparation phase. Major focus was placed on the individual surface design. The authors try to present and compare chosen solutions of surface design, highlighting the pros and cons caused by this approach

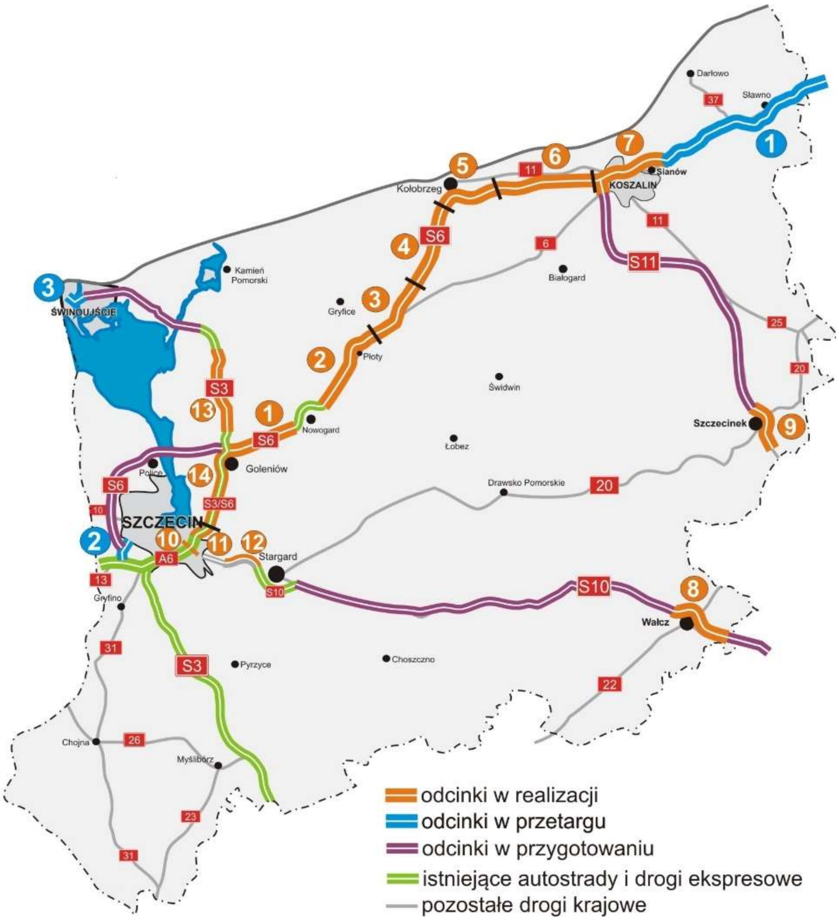
Keywords: Pavement; Design and build

Introduction

The "Design-Build" investment system, unlike the classic "build" system, transfers a significant part of the risk related to the construction intention directly to the contractor. It is he who is responsible for both the project and the subsequent implementation. This approach allows the use of the most optimal technologies in the investment (from the point of view of the contractor). It involves cost optimization and theoretically lower final price. For its part, the Contractor must ensure that the technical requirements imposed by the Investor are maintained and, as a rule, longer warranty periods. Implementations of the expressway on the section of Goleniów - Koszalin were conducted in the "design-build" formula. Agreements were signed from September to November 2015. The contractual value of the concluded contracts is PLN 2 107 693 535. One fragment, on the analyzed S6 expressway - Nowogard bypass - was commissioned in December 2011. Basic technical parameters of the road being built [6]:

- design speed - 100 km / h
- authoritative speed - 110 km / h
- load on the surface - 115 kN / axle
- number of lanes - 2 x 2
- road width - 2 x 7.0 m
- width of the emergency belt - 2.5 m
- width of ground shoulders - 2 x 0.75 m
- width of the dividing belt - 4.0 m (plus two bands with a width of 0.5 m each)
- engineering structures along the expressway - load class A

In the design work on all analyzed 6 sections marked from 1 to 6 (Figure 1), the Employer allowed the individual design of the road surface. The contractors took advantage of this opportunity by presenting different pavement designs. In this article, individual structures will be analysed.



1. The course of the S6 road being built along with the division into sections - orange [6]

Design traffic on the S6 expressway

The starting point for pavement design is the adoption of an appropriate number of equivalent standard axes in the design period, which is 30 years for expressways. This value is assumed based on the traffic forecast or in accordance with the investor's expectations specified in the functional and operational program (PFU). In the analyzed case, in the PFU, the traffic category of KR6 was required on each of the sections. At the same time, it was specified that the binding material constituting the order description is the traffic forecast developed by the contractor of the Design Concept. Flexible structures are given in the Catalog of Typical Paving and Semi-rigid Surfaces (hereinafter the catalog) [2] cover the entire range of planned traffic, which for the traffic category KR6 is 22.0 - 52.0 million [1]. The approval of individual design resulted in determining the total number of equivalent 100 kN standard axes based on the traffic forecast. The comparison of traffic planned on individual sections is summarized in Table 1.

Tab. 1. Comparison of project traffic and traffic categories for individual sections

Section	1	2	3	4	5	6
Number of standard axles [mln]	24,4	24,5	26,0	19,5 (22,0)*	23,1	22,4

Traffic category according to the forecast	KR6	KR6	KR6	KR5/KR6*	KR6	KR6
Traffic category according to PFU	KR6	KR6	KR6	KR6	KR6	KR6

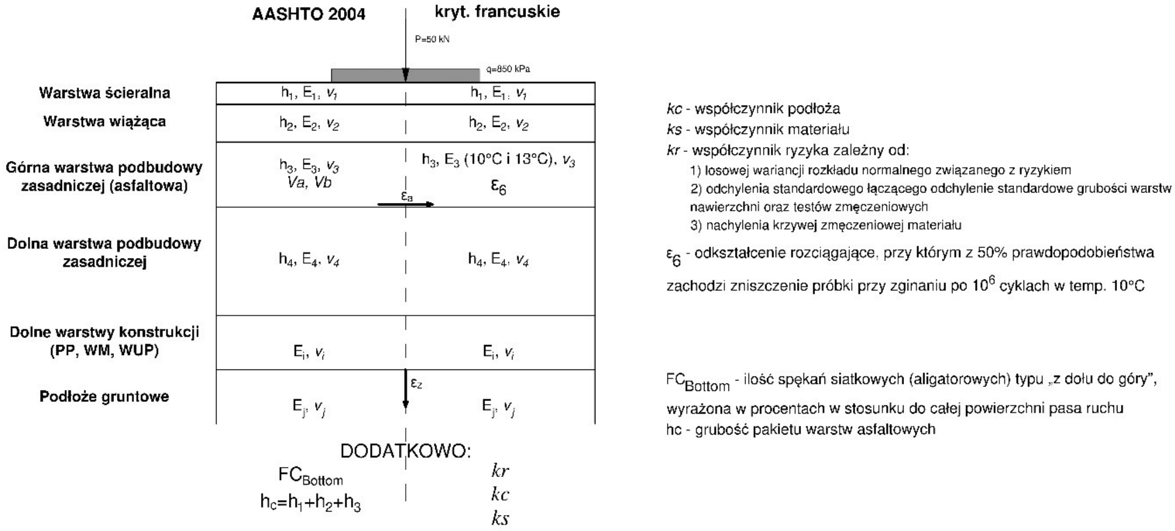
* Finally, the value of 22 million axes was adopted - the lower range of KR6

Based on the data contained in Table 1, it should be stated that the forecasted traffic load on the entire S6 expressway is located in the lower category of the KR6 traffic category. Therefore, all sections in terms of the required fatigue life are similar to each other. In the case of one episode, the designated traffic was slightly smaller than the lower range of the KR6 traffic category, but eventually, the number of standard axes on the level of 22 million was assumed. The adopted design traffic between individual sections did not differ more than by 10%. The designated traffic load allowed the Contractors to "optimize" constructions in relation to catalog solutions.

Designed individual surfaces on the example of the S6 expressway

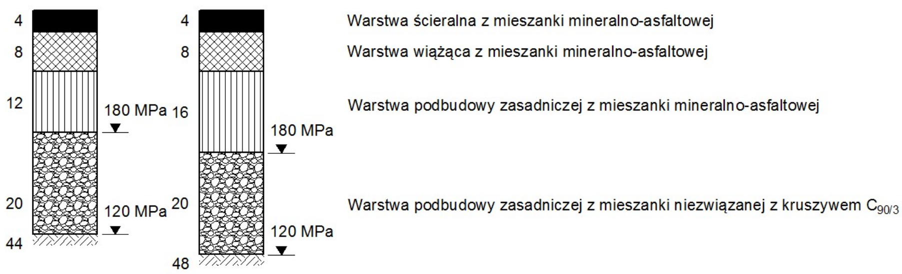
Contractors on each section approached the design problem in a different way. On two episodes from six, solutions similar to catalogs in the scope of layering and materials were used, with the thickness of the layers in relation to the catalog being reduced. Thus, adjusting the thickness of the pavement structure to the projected traffic load. In the case of the aforementioned sections, it was decided to apply to the upper layer of the main asphalt concrete (AC) foundation. On three other sections in the bottom layer of the foundation, it was decided to use asphalt concrete with a high stiffness modulus (AC WMS), on these sections there was a significant reduction in thickness relative to the catalog. In one case, constructions using a thin anti-fatigue layer (AC AF) were used to design pavements based on long-lived pavement concepts [7]. The investor based on the presentation of road pavement projects received 6 different structures differing not only in thickness but also in the materials used, including in one case with the anti-fatigue layer, not used so far in the Zachodniopomorskie voivodeship.

The pavement construction designs presented for approval by the Engineering Department team had to include relevant calculations supporting the adopted assumptions. Due to the use of different materials, the calculation methods and more strictly fatigue criteria for asphalt layers also had to differ. In the case of traditional bituminous concretes used in the foundation layer, the criterion used in the design was AASHTO 2004 used in the catalog and described in more detail in [1]. In the case of the remaining sections, the French criterion [1], [3] was used, as best suited to asphalt concretes with a high stiffness modulus and AC AF blends. The fatigue criteria used differ from each other in relation to the data needed to perform the relevant calculations, first and foremost the differences can be observed in the parameters of asphalt mixtures. In the AASHTO 2004 criterion, in addition to the thickness and modulus of stiffness for fatigue durability, the volumetric content of free spaces and asphalt and the adopted FCBottom coefficient concerning the number of mesh cracks on the pavement surface. In the case of the French criterion, the stiffness and thickness modulus is also the leading parameters, but there are also tensile strains $\varepsilon 6$. This parameter should be specified in the test, in which the schematic is bending of the trapezoidal beam support (in Poland a four-point bending beam scheme is used). In addition, risk factors, material and substrate factors should be taken into account in the calculations (Figure 2).



2. Comparison of the criteria: AASHTO 2004 and the French criterion

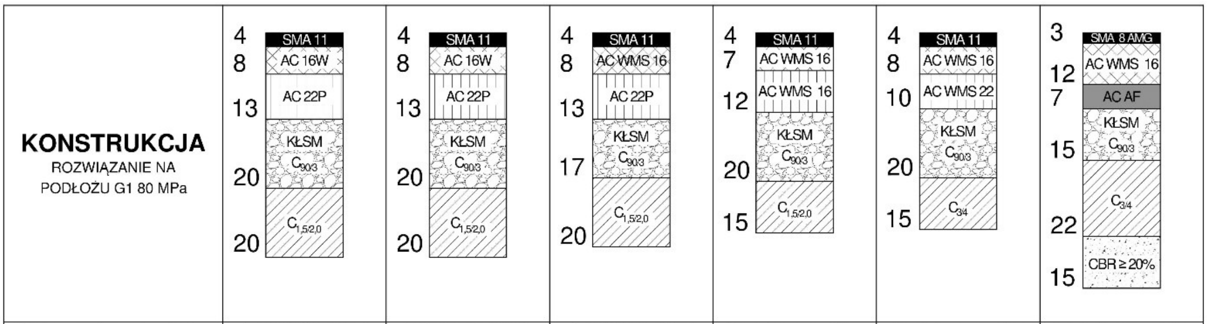
The comparative analysis of the surface structure of the S-6 expressway on individual sections should begin with the presentation of a typical structure for the traffic categories KR5 and KR6 according to the catalog (Figure 3).



3. The design for motion KR5 and KR6 in accordance with the Catalog of Typical Prompt and Semi-rigid Structures

The total thickness of asphalt layers with a typical structure for the KR6 movement, at the foundation of a mixture unrelated to $C_{90/3}$ aggregate is 28 cm. The thickness of asphalt layers at the KR5 traffic category is 24 cm. As already mentioned, the catalog constructions fully cover the scope of a given category of traffic, the constructions of asphalt layers with a thickness in the range of 25 - 28 cm have fatigue durability in the range of the KR6 traffic category. This assumption is correct in the situation of suitably selected lower layers of the structure and the improved substrate.

Figure 4 shows the constructions designed on the S6 expressway. The individual solutions were arranged from the thickest (in terms of bituminous layers) to the thinnest.



Wykorzystane kryterium	AASHTO 2004	AASHTO 2004	AASHTO 2004	kryt. francuskie	kryt. francuskie	kryt. francuskie
Grubość warstw asf.	25 cm	25 cm	25 cm	23 cm	22 cm	22 cm
Grubość łączna na G1	65 cm	65 cm	62 cm	58 cm	57 cm	74 cm
Uwagi:	Warstwa podbudowy o zmniejszonej zawartości wolnych przestrzeni oraz zwiększonej zawartości asfaltu względem WT-2	Warstwa podbudowy o zmniejszonej zawartości wolnych przestrzeni oraz zwiększonej zawartości asfaltu względem WT-2	Warstwa podbudowy o zmniejszonej zawartości wolnych przestrzeni oraz zwiększonej zawartości asfaltu względem WT-2			Warstwa AC AF oraz AC WMS na asfalcie modyfikowanym

4. Comparison of designed structures on the S6 expressway

The largest thickness of asphalt layers was 25 cm and this thickness was designed on three sections. In this case, the AASHTO 2004 criterion was used. In one of the three constructions, an asphalt concrete with a high stiffness modulus was provided in the binding layer. In each of the three constructions calculated AASHTO 2004 criterion, the lower asphalt layer (foundation) was modified in relation to WT-2 [4], [5] by reducing the volume of free space and increasing the asphalt content. The other three constructions have been designated based on the French criterion. The thickness of the asphalt layers was 22-23 cm. In the lowest asphalt layer, asphalt concrete with a high stiffness AC WMS (2 constructions) and a non-standard mixture, AC AF (anti-fatigue) were used. In the case of a structure designed using the long-life pavement concept, a binder course of high modulus of rigidity was used between the abrasive layer and the foundation (AC AF layer). This construction is also characterized by the thinnest wear layer (3 cm) made of a mixture of SMA 8 and a rubber modified binder. Small differences occur in the bottom layer of the main foundation from the mixture unrelated to $C_{90/3}$ aggregate. The thickness of this layer is from 15 cm (1 construction) through 17 cm (1 construction) to 20 cm (4 constructions). The lower layers (improved sub-floor / sub-foundation) were made of mixtures bound with a binder. The thickness of these layers ranged from 15 cm to 22 cm, depending on the design, mixtures based on $C_{1.5/2.0}$ class binder were used, or $C_{3/4}$.

Analyzing the above constructions, it should be stated that none of the presented solutions, both in relation to the thickness of the layers and the materials used, are compatible with the catalog solutions. These changes are significant and are not limited to thickness, but also to the parameters of asphalt mixtures. In three constructions, when determining the fatigue life, a different criterion of asphalt layers was used than in the catalog. In the case of one construction, it was decided to design the structure based on the concept of long-life pavement.

Summary and Conclusions

From the point of view of fatigue durability of the surface, the lower layers of the structure and the improved substrate are also important. According to the generally prevailing methodology, they were adopted depending on soil and water conditions. However, the authors focused only on the layers of the upper structures. Analyzing individual solutions, as well as the process of approving projects and realizing the surface, the following conclusions can be made:

1. contracts carried out in the "design-build" formula may lead to a reduction of the investment project costs while transferring part of the risk to the contractor,

2. the Contract Engineer team and the investor must have adequate staff to verify the design solutions presented and to control construction works, including the enforcement of key non-standard design solutions,
3. in the case of long sections of roads divided into smaller contracts, the admission of individual pavement design may entail a considerable diversification of the pavement structure which may contribute to the more difficult maintenance of the surface and its renovations,
4. in the case of implementation of various pavement structures by different contractors, there is a problem of a suitable connection on the contact sections,
5. designer in the formula "design-build" is given economic pressure while having to meet contractual requirements and technical correctness of accepted solutions.

Source materials

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