MATEC Web of Conferences **122**, 04002 (2017) DOI: 10.1051/matecconf/201712204002
GAMBIT 2016

New Polish catalogue of typical flexible and semi-rigid pavements

Józef Judycki[1], *Piotr* Jaskuła[1,*], *Marek* Pszczoła[1], *Dawid* Ryś[1], *Mariusz* Jaczewski[1], *Jacek* Alenowicz[1], *Bohdan* Dołżycki[1], and *Marcin* Stienss [1]

[1]Gdansk University of Technology, Faculty of Civil and Environmental Engineering, Gdansk, Poland

Abstract. The paper covers the following topics important for the development of the new Polish Catalogue of typical flexible and semi-rigid pavements: reasons for preparing the new issue of the Catalogue of typical flexible and semi-rigid pavements, items introduced in the new issue, organise the terminology related to pavements, design traffic calculations and new equivalent axle load factors, new materials and technologies included in the Catalogue, classification of subgrades based on the soil material and drainage conditions, designing of lower layers and improved subgrade, designing of the main, upper layers.

1 Introduction

“The Catalogue of Typical Flexible and Semi-rigid Pavements” is one of the main design and construction guides used by road engineers in Poland. The previous issue of the Catalogue was published in 1997. Since then considerable technological developments in the area of road construction have been observed. They were accompanied by the introduction of new standards and technical requirements consistent with the requirements of the European standards. The requirements set out for road construction materials have also changed. New materials have been authorised for use in paving work. Traffic levels today are much higher than in the mid 1990s and gross weights and axle loads have also considerably increased. The dimensions and weights of vehicles are now limited by new regulations co-ordinated with the EU Directive. The changes include higher permitted loads transmitted on the pavement by single axles and by sets of axles. A weighing-in-motion scheme was implemented on the road network and the number of measurement sites is still increasing. This was accompanied by developments in pavement design methods and in testing of pavement structures and road construction materials. More attention is now paid to sustainable development, protection of the natural environment, limiting consumption of energy and recycling of materials. All these changes and developments called for preparing a new issue of the Catalogue. Hence, the team from the Department of Road Engineering of Gdansk University of Technology was employed by the Polish highway agency – GDDKiA to prepare a new edition of the Catalogue. After a few years of research the Catalogue was finalised in March 2013.

* Corresponding author: pjask@pg.gda.pl

2 What is new in the 2014 issue of the Catalogue

There are a number of differences between the new issue of the Catalogue, further referred to as the new issue, and the previous issue of 1997. Attention is drawn to the following main changes:

- Modified and more accurate definitions of terms relating to flexible and semi-rigid pavements.
- 30-year pavement design life adopted for motorways and trunk roads. For other roads the 20-year design life of pavement remained unchanged. A more accurate new calculation method of design traffic and introduction of a new traffic class - KR7 for design traffic much heavier than the current limits. These changes were caused by the growth of road traffic in Poland.
- Some minor changes in soil bearing capacity classification and the secondary deformation modulus E2 has been added for subgrade classification purposes. The new issue requires verification of the design assumptions by checking the bearing capacity of soil at the construction stage i.e. after stripping of topsoil - for cut sections or on completion of embankments - for fill sections.
- Three bearing capacity classes have been assumed on top of the lower pavement courses, under the base course. The class is specified in relation to calculated traffic class. The rules for using the separation and drainage layers have been organised.
- Various design and construction options are described for the lower pavement courses and improved subgrade.
- New materials and technologies have been introduced. They include: thin layer asphalt surfacing, open-graded porous asphalt, recycled and other man-made materials and materials bound with hydraulic binders. There are new requirements concerning materials, formulated in compliance with the European Standards.
- The typical pavement structures defined in the new Catalogue 2014 were designed with the application of the mechanistic-empirical method including new fatigue criteria. The results were compared to typical pavement structures used in other countries with similar weather conditions. The experiences gained over the years in Poland have also been taken into consideration.

3 New schematic diagram and terminology related to pavement structure

A big challenge during the work on the new issue of the Catalogue were serious discrepancies in the technical terms used in relation to the pavement courses in various Polish documents. This situation caused problems in the design, construction and invoicing phases of projects. The terminological studies resulted in some alterations in the terminology used so far. The final result is presented in Fig. 1. The pavement structure is divided into two layer packages - upper courses and lower courses. Improved subgrade is part of earthworks. Moreover, the base layer is divided into upper base layer and lower base layer.

Pavement structure	Upper pavement courses	Wearing course		
		Binder course		
		Base	Upper base layer	
			Lower base layer	
	Lower pavement courses	Subbase		
		Capping layer		
Subgrade	Improved (stabilised) subgrade			
	Original soil in cut or embankment in fill of bearing capacity class G1-G4			

Fig. 1. Schematic diagram and terms relating to courses of flexible and semi-rigid pavement structures and improved subgrade.

4 Traffic load calculation and design traffic classification

In the new issue of the Catalogue there are seven classes of traffic which might be applied in the design of a road pavement (from KR1 – lightest to KR7 – heaviest). The class is chosen on the basis of the design traffic. The design traffic volume is defined as the cumulative number of equivalent single axle loads (ESAL) of 100 KN per traffic lane during the whole design life. The design traffic is calculated with the following equation:

$$N_{100} = f_1 \cdot f_2 \cdot f_3 \cdot (N_C \cdot r_C + N_{C+P} \cdot r_{C+P} + N_A \cdot r_A) \quad (1)$$

where:
- N_{100} – design traffic being the cumulative number of equivalent standard axles of 100 kN per traffic lane during the design life,
- N_C, N_{C+P}, N_A – cumulative number of HGVs without trailers (C), HGVs with trailers or semitrailers (C+P) and coaches and buses (A) during the design life,
- r_C, r_{C+P}, r_A – load equivalency factors (LEF) to convert the numbers of HGVs without trailers (C), HGVs with trailers (C+P) and coaches (A) to the number of 100 kN ESAL,
- f_1 – load distribution factor of design lane, f_2 – lane-width factor, f_3 – longitudinal gradient factor.

In the new issue of the Catalogue the load equivalency factors r_C, r_{C+P}, r_A were determined on the basis of the available weigh-in-motion data. Weighing in motion (WIM) is a continuous process, providing complete data on heavy traffic, including vehicle type identification, axle loads, axle configuration, vehicle dimensions and speed. The pavement loading investigation was carried out using the measurement data obtained from weighing of over 4.2 million HGVs. The analysis of traffic included a determination of axle load and gross weight distributions, distribution by vehicle type, annual, weekly and daily traffic load distributions and the percentage of overloaded vehicles [1,2]. The most important element of the research was evaluation of the severity of vehicle influence on the pavement structure, represented by the load equivalency factors. Their values were calculated for each recorded vehicle using the following methods: AASHTO [3], fourth power law, French method [4] and method developed at the Gdańsk University of Technology [5]. Parameters determining the severity of the vehicle's action on pavement structure, appropriate to the method were taken into account, including: axle spacing (relevant to tandem and tridem axles), type of pavement (flexible or semi-rigid) and thickness of pavement courses and finally tyre-pavement contact stresses. The final values of load equivalency factors for vehicle classes were determined through static analysis of the load equivalency factors of individual vehicles, taking into account weight and axle load variations depending on the maximum legal load and class of road. Some safety margin was added to account for different load application parameters on different roads, possible vehicle overloading, future increase in gross weights and axle loads of vehicles as well as the dynamic effects.

Table 1. Comparison of the load equivalency factors provided in the 2014 and 1997 issues of the Catalogue of Flexible and Semi-rigid Pavements

Vehicle class	2014 issue				1997 issue
	Road type and the legal limit of single axle load				
	Motorways and trunk roads (115 kN)	National roads (115 kN)	Other roads (115 kN)	Other roads (100kN)	
HGV without trailer – **C type**	0.50	0.50	0.45	0.45	0.109
HGV with trailer – **C+P type**	1.95	1.80	1.70	1.60	1.245 1.950
Coaches and buses – **A type**	1.25	1.20	1.15	1.05	0.594

The new issue of the Catalogue introduces factors accounting for the influence of road geometry on design traffic, namely the lane width factor f2 and the longitudinal gradient factor f3. Their values depend on traffic lane width and longitudinal slope.

5 New road construction materials and technologies recently introduced in Poland

The main changes concerning construction materials and technologies in relation to the 1997 issue of the Catalogue [6] include:

- New asphalt mixtures authorised for wearing course construction: stone mastic asphalt (SMA) and porous asphalt (PA) applied in one or two layers [7].
- Wider use of partly crushed material for production of unbound base mixtures. So far, it was a common practice to specify only fully crushed material for road base construction.
- Use of cold-mix recycling for production of base mixtures (mineral-cement-emulsion mixture and mineral mixture treated with foamed bitumen) for pavements for KR1-KR4 traffic classes [8]. These materials were not specified as suitable for new constructions in the 1997 issue of the Catalogue [6].
- The required strength class for hydraulically bound materials for base and sub-base courses is defined by traffic class of the road concerned. Previously the strength requirement was the same for all traffic classes, but dependant on course function (base/subbase).
- Use of hydraulic road binders for treatment of aggregate and soil layers apart from the previously used binders, which were: cement, slag and fly ash. Hydraulic road binders combine the desirable characteristics of cement, fly-ash and lime and are currently among the most used soil and aggregate binding agents. By binding and reducing moisture of the stabilised material these materials give very good results in a relatively short time.
- Mixing-in-place as a recommended stabilisation treatment for hydraulically bound lower courses of pavement and improved subgrade. This was possible due to great popularity of modern mobile auger mixing machines, which ensure the required quality parameters of stabilised material.

The requirements relevant to fatigue resistance of pavement structure are given in the Catalogue [9] for most of the materials. In case of other requirements the reader is referred to relevant Polish regulations, which provide detailed specifications for all road construction materials. Individual pavement design is also allowed under certain circumstances, thus opening the door for a wider use of newly developed technologies.

6 Evaluation of the subgrade soil and ground water conditions

The new issue of the Catalogue [9] introduced a number of changes to the procedure of evaluation of the subgrade soil and ground water conditions. This has been caused mainly by the developments in subgrade testing and strengthening methods. The main changes include:

- Subgrade under earthen structure (i.e. embankments) is clearly distinguished from the subgrade under a pavement structure,
- New depths for analysing subgrade conditions under pavements: 2 m for checking ground water conditions and 1 m for checking soil conditions, measured from the underside of pavement structure.
- Secondary deformation modulus E2 was added to the previously used bearing capacity evaluation criteria (CBR, frost heave susceptibility and drainage conditions).
- Obligatory verification of the design input assumptions during the progress of construction by comparing the modulus E2 measured on the subgrade surface with the value adopted as input for design. A lower than assumed value of E2 obtained in such verification requires re-designing of the lower pavement courses.

7 Designing the lower courses of pavement and the layer of improved subgrade

The Catalogue issue of 1997 gave a very limited choice in this question, which was generally between treatment of subgrade with cement or replacement of soil. It was established in a review of methods used in other countries that engineers are allowed to use different stabilisation systems which are appropriate for traffic loads and the required value of modulus on top of the subgrade. This way a stabilisation technique can be chosen which is the most appropriate for the local soil and water conditions. An example of a deficiency in the previous issue of the Catalogue (1997) was prescribing the same stabilisation depth and strength for two different values of secondary deformation modulus after treatment (100 MPa and 120 MPa) and treating G1 bearing capacity class as equivalent to meeting these requirements. Accordingly, no treatment was needed for subgrades built of materials such as fine sand. In the new Catalogue these provisions were verified and the above-mentioned simplifications and deficiencies were eliminated. The minimum value of E2 measured on top of the improved subgrade layer was introduced as $E2 \geq 50$ MPa. The value of E2 required on top of the lower pavement courses: sub-base and/or capping layer depends on the traffic class of the road. These are: $E2 \geq 80$ MPa for traffic classes KR1-2, $E2 \geq 100$ MPa for traffic classes KR3-4, and $E2 \geq 120$ MPa for traffic classes KR5-7.

The BISAR computer programme was used to evaluate and design different lower pavement course systems, represented by an elastic layered half-space model. For each layer appropriate values of E-modulus and Poisson ratio were specified. Elastic deflections on the top of the improved subgrade and on the top of the lower courses of pavement were determined for each analysed system. The value of equivalent modulus of elasticity Eeq on the top of the analysed layered systems were calculated using the Boussinesq's equation. Computations were conducted for 14 different systems of lower courses of pavement and improved subgrade and for all bearing capacity classes of subgrade - from G4 to G1. Some typical arrangements (types 1-4) for traffic categories KR5-7 and G4 bearing capacity class are presented in Fig. 2.

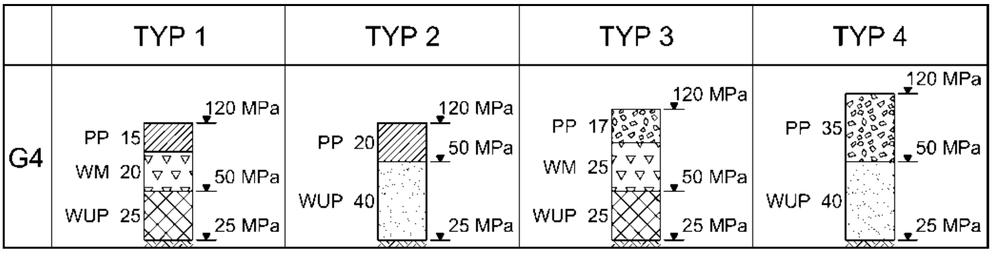

Fig. 2. Some typical arrangements (types 1-4) for traffic categories KR5-7 and G4 bearing capacity class of subgrade (PP – sub-base, WM – capping layer, WUP – improved subgrade layer)

The new issue of the Catalogue specifies thicker solutions as compared to the 1997 issue which, however, are in compliance with those currently used in other countries.

8 Upper courses of pavement

Taking into account the developments in the use of paving materials since the date of publication of the design methods recommended in the previous Catalogue it was decided that the use of Asphalt Institute [10], Shell [10] and AASHTO 1993 [3] methods will be limited to preliminary calculations and the results will be treated as supplementary. For a further application the fatigue criteria from the mechanistic-empirical methods AASHTO 2004 [11][12] and (partly) from the French method [13][14] were selected. Due to a lack of detailed data from laboratory testing of materials it was not possible to use the subgrade strain criterion from the AASHTO 2004 and the previously used subgrade deformation criterion of the Asphalt Institute method was chosen instead.

The stress and strain calculations in the pavement were carried out according to the theory of elastic layered half-space. An assumption that a single axis transmits the load through two single wheels, represented by circular contact area of P=50 kN load and q=850 kPa tyre-pavement contact pressure was assumed in the calculations as appropriate for contemporary heavy goods vehicles.

The design criteria used for flexible pavement design were: bottom-up fatigue cracking of asphalt layers, according to the latest AASHTO M-ENPDM method of 2004 (see equations 2 and 3) [11] and permanent deformation according to the Asphalt Institute method of 1982 [10] The number of load applications until the development of fatigue cracking in asphalt layers was calculated with the following equation:

$$N_f = 7{,}3557 \cdot (10^{-6}) \cdot C \cdot k_1' \cdot \left(\frac{1}{\varepsilon_t}\right)^{3{,}9492} \cdot \left(\frac{1}{E}\right)^{1{,}281} \tag{2}$$

where:
- N_f – number of load repetitions until the development of fatigue cracking on 50% of the overall surface area of traffic lane,
- k_1' – calibration constant depending on the asphalt layer thickness and type of fatigue cracking,
- ε_t – tensile strain at the critical point in the vertical cross-section of pavement, -,
- E – stiffness modulus of asphalt layer, MPa,
- C – coefficient depending on the volumetric parameters of asphalt mixture calculated as $C = 10M$, in which M is calculated as follows:

$$M = 4{,}84 \cdot \left(\frac{V_b}{V_a+V_b} - 0{,}69\right) \tag{3}$$

where:
- V_b – effective content of bitumen, % v/v,
- V_a – air voids content, % v/v.

The AASHTO 2004 criterion represented by equations (2) and (3) is based on the number of load repetitions until the development of fatigue cracking on 50% of the overall surface area of the traffic lane. However, by rearranging the above equations it is possible to calculate the number of load applications for any level of development of fatigue cracks. The following cracking severity levels were adopted for the purpose of the performed analyses: 10-20% for pavements with unbound base and 5-10% for full-depth asphalt pavements.

According to the conduced calculations and analyses all thicknesses of the upper pavement courses are sufficient to fully cover the load ranges in the respective traffic classes of roads. In comparison to the Catalogue issue of 1997 the new issue of 2014 provides more typical options for the design of upper courses in pavement structures with unbound base. What is completely new are typical pavement structures with cold recycled base and the use of porous asphalt in bituminous courses. The thicknesses of the upper courses of typical pavement structures are presented in Table 2.

Table 2. Thicknesses of the upper courses of typical pavement structures given in [9]

No.	Type of pavement	Thickness of the upper courses of pavement, cm							
		Pavement course	Traffic class, KR						
			1	2	3	4	5	6	7
1.	Flexible	Asphalt layers	9	12	16	20	24	28	30
		Unbound base, $C_{90/3}$	20	20	20	20	20	20	20
2.	Flexible	Asphalt layers	9	12	16	20	24	28	30
		Unbound base, $C_{50/30}$	22	22	22	22	22	22	22
3.	Flexible	Asphalt layers	9	12	-	-	-	-	-
		Unbound base, C_{NR}	25	25	-	-	-	-	-
4.	Flexible	Asphalt layers and base	14	18	22	26	30	34	36
5.	Flexible	Asphalt layers	8	12	12	16	-	-	-
		Mineral/cement/ emulsion/ FBit base	15	15	20	20	-	-	-
6.	Semi-rigid	Asphalt layers	9	11	15	18	20	22	24
		Hydraulically-bound base	18	20	20	22	22	24	24
7.	Semi-rigid	Asphalt layers	9	11	-	-	-	-	-
		Hydraulically treated soil base	18	20	-	-	-	-	-

9 Conclusions

The new Catalogue of typical flexible and semi-rigid pavements [9] provides new load equivalency factors (to convert vehicles to equivalent single axle load applications), defines a new traffic category, extends the design life period for motorway and trunk road pavements, considerably modifies the existing soil subgrade treatment methods and adds new ones, introduces new materials, including recycled materials for use in the construction of upper and lower courses of pavement and for improved subgrade. Moreover, it includes provisions intended to reduce considerably the problem of reflective cracking in semi-rigid pavements.

Safety margins are applied to the following issues included in the Catalogue: traffic calculation method, mechanical properties of asphalt and hydraulically-bound base layers, methodology of adopting a standard Catalogue pavement structure included in the Catalogue and selection of construction tolerances.

The new issue of the Catalogue offers a much wider choice of different systems and construction methods allowing for their adjustment to suit local conditions.

References

1. D. Ryś, J. Judycki, P. Jaskuła, Determination of Vehicles Load Equivalency Factors for Polish Catalogue of Typical Flexible and Semi-rigid Pavement Structures, Transp. Res. Procedia. **14** pp. 2382–2391 (2016). doi:10.1016/j.trpro.2016.05.272
2. D. Ryś, J. Judycki, P. Jaskuła, Analysis of effect of overloaded vehicles on fatigue life of flexible pavements based on weigh in motion (WIM) data, Int. J. Pavement Eng. **17** pp. 716–726 (2016). doi:10.1080/10298436.2015.1019493
3. AASHTO, Guide for Design of Pavement Structures (AASHTO, USA, 1993)
4. J.F. Corte, et al., Conception et dimensionnement des structures de chaussee (LCPC, 1994)
5. J. Judycki, A. Grajewska, et al., Recommendations for calculating the load equivalency factors for flexible and semi-rigid pavements (Gdańsk University of Technology, Highway Agency (GDDKiA), Gdańsk, 2006)
6. Catalogue of typical flexible and semi-rigid pavements (IBDiM, GDDKiA, Warsaw, 1997)
7. B. Świeczko-Żurek, P. Jaskuła, J.A. Ejsmont, A. Kędzierska, P. Czajkowski, Rolling resistance and tyre/road noise on rubberised asphalt pavement in Poland, Road Mater. Pavement Des. **18** pp. 151–167 (2017). doi:10.1080/14680629.2016.1159245
8. B. Dołżycki, M. Jaczewski, C. Szydłowski, The Influence of Binding Agents on Stiffness of Mineral-cement-emulsion Mixtures, Procedia Eng. **172** pp. 239–246 (2017). doi:10.1016/j.proeng.2017.02.103
9. J. Judycki, P. Jaskuła, M. Pszczoła, J. Alenowicz, B. Dołżycki, M. Jaczewski, D. Ryś, M. Stienss, Catalogue of typical flexible and semi-rigid pavements (Gdańsk University of Technology, 2013)
10. J. Judycki, Comparison of fatigue criteria used in the design of flexible and semi-rigid pavements in relation to the new issue of the Polish Catalogue of flexible and semi-rigid pavements (Part 1), Road Eng. **1** pp. 5–18 (1999)
11. J. Judycki, Building and calibration of models to investigate fatigue cracking in bituminous road pavements designed with the mechanistic-empirical method AASHTO 2004, Drog. I Most. **4** pp. 31–53 (2011)
12. J. Judycki, Models to investigate fatigue cracking in bituminous road pavements designed with the mechanistic-empirical method AASHTO 2004, Road Eng. **11** pp. 343–347 (2011)
13. M. Jaczewski, J. Judycki, Adaptation of the French fatigue criteria for designing of flexible pavements in Poland, Road Eng. **5** pp. 164–170 (2012)
14. M. Jaczewski, J. Judycki, Application in Poland of the French method for designing bituminous pavements including hydraulically bound roadbase, Road Eng. **6** pp. 199–203 (2012)