Comparative Analysis of Environmental Impacts of Municipal Road Structures

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Abstract. The objective of the study is the environmental assessment of construction solutions for concrete paving. In the study, unit environmental indicators for selected road construction solutions for the KR1 traffic have been determined. The considerations include road constructions with substructures made of: lean concrete, cement bound soil and crush-stone aggregate. Seven key environmental indicators were adopted for the evaluation as recommended by the PN-EN 15643-2:2011 standard "Sustainability of construction works. Part 2: Framework for the assessment of environmental performance": global warming potential (GWP), ozone depletion potential (ODP), acid-generating potential (AP), eutrophication potential (EP), photochemical ozone creation potential (POCP), abiotic depletion potential for nonfossil resources (ADPE), abiotic depletion potential for fossil resources (ADPF). The weights were adopted on the basis of the DTT method, assessing the distance of EU domestic impacts from the desired state set by EU binding policy targets.

Such evaluation enabled the prioritisation of concrete roads construction solutions from the point of view of environmental impact. The obtained measurements may be a part of the evaluation for the road investment projects. The presented approach disseminates sustainable design patterns in the area of engineering practice with the implementation of requests of the United Nations Framework Convention on climate change.

Keywords: Concrete pavements · LCA · ILCD · Impacts on the environment

1 Introduction

Concrete pavements have no established tradition in Poland despite that the first such surfaces appeared already in 1912. In Poland the vast majority of roads are still made of bitumen, despite the many benefits of concrete pavements, which include: high load rating and the load-carrying capacity ability, resistance to permanent deformations, bright colour (improving safety), good operating characteristics, low maintenance costs. A properly designed and constructed pavement usually reaches a 20-year, even a 30-year period has become a standard. The advantages of concrete pavements demonstrate that they should gain popularity and become a complement to the selection of available technologies next to bitumen surfaces, cobblestone surfaces and other,

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especially for municipal roads, which account for around half of all roads in Poland. In addition, due to its technological simplicity, they can be constructed by small local companies [20].

Contemporary trends for the socio-economic development, however, require the consideration of social and environmental aspects next to the technological and design aspects during design process, hence the construction of concrete pavements should be covered by a new design approach that takes into account all the requirements of sustainable construction, i.e. integrated life cycle design (ILCD - integrated life - cycle design) [16, 22, 24].

The new approach combines the design at the material, construction element and the whole construction level and then considers the selected criteria from the areas relevant to sustainable development at each of these levels - including those that reflect the impact of the object on the environment. In practice, there is no finished template for the evaluation and raising the efficiency of the environmental design solutions. The study presents the variant analysis of the solutions with the use of basic environmental indicators which form the evaluation criteria.

2 Materials and Methods

The environmental impact assessment (EIA) is a structured way of conduct based on interdisciplinary identifying and assessing the impact of the planned measures and their alternatives on a specific area and its processes [1]. For an environmental assessment of construction works in accordance with PN-EN 15643-2:2011 [8], the recommended approach is the LCA method.

The subject of the analysis are the structures of concrete pavement with sub-structure made of:

– cement bound soil (cement-stabilised soil) (W1),
– mechanically stabilised crush-stone aggregate (W2),
– lean concrete (W3) (Fig. 1).

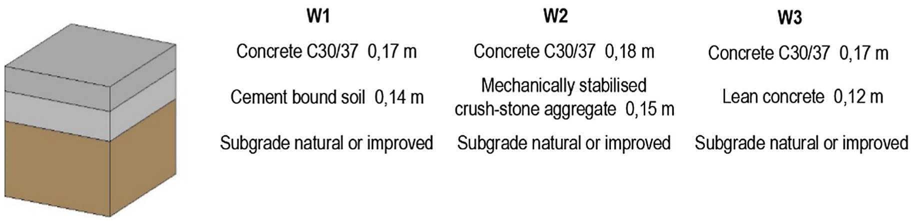

Fig. 1. Variants of the design solutions to be evaluated

In the study the unit indicators - listed on 1 km of road with a width of 5 m - were adopted. The presented evaluation has the *cradle to gate* character includes the production phase (modules A1–A3) [7]. 7 key environmental indicators (categories) were adopted for the evaluation of variants as recommended by the PN-EN 15643-2:2011 standard "Sustainability of construction works. Part 2: Framework for the assessment of environmental performance" shown in Table 1. The weights for the category (w_k) were adopted on the basis of the DTT method, assessing the distance of EU domestic impacts from the desired state set by EU binding policy targets. (Table 1) [3]. DTT method gives you the ability implement the requirements of the United Nations Framework Convention on Climate Change (UNFCCC), the objective of which is to achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

Table 1. Evaluation categories, normalization factors, weights

Category	Unit	Normalization factor	Weight
Global warming potential (GWP)	kg CO_2 eq.	1.23E+04	1.16
Ozone depletion potential (ODP)	kg CFC11 eq.	2.20E–01	1.05
Acid-generating potential (AP)	kg SO_2 eq.	7.12E+01	1.18
Eutrophication potential (EP)	kg $(PO_4)^3$ eq.	3.25E+01	1.14
Photochemical ozone creation potential (POCP)	kg ethene eq.	2.15E+01	1.28
Abiotic depletion potential for nonfossil resources (ADPE)	kg Sb eq.	3.91E+01	1
Abiotic depletion potential for fossil resources (ADPF)	MJ, (net)	2.73E+05	1

The measure of the assessment is ultimately the E_P value, which is the weighted sum of the standardised values of the environmental categories (N_K) :

$$E_p = \sum\nolimits_k^m N_k \cdot w_k \tag{1}$$

The data for the evaluation was adopted on the basis of the environmental product declarations (EPD) [1–5, 7–13, 16–24]. In view of the diversity of the raw materials extraction technologies (A1) and their processing (A3) and also of the differentiated transport distances in the A2 module, for the solutions ranking the average Ep values were adopted for several material suppliers to build the substructure. The evaluation variance were also analysed.

In the first variant the quantity of cement (c) in kg per 1 m^3 of the stabilised ground was calculated according to the formula [8]:

$$c = \rho_{ds} \cdot x \tag{1}$$

where ρ_{ds} is the soil bulk density (adopted: 1850 kg/m^3), x - percentage addition of cement (adopted: 0.03).

3 Results

3.1 Evaluation Results

The results of the design evaluations were presented in Fig. 2.

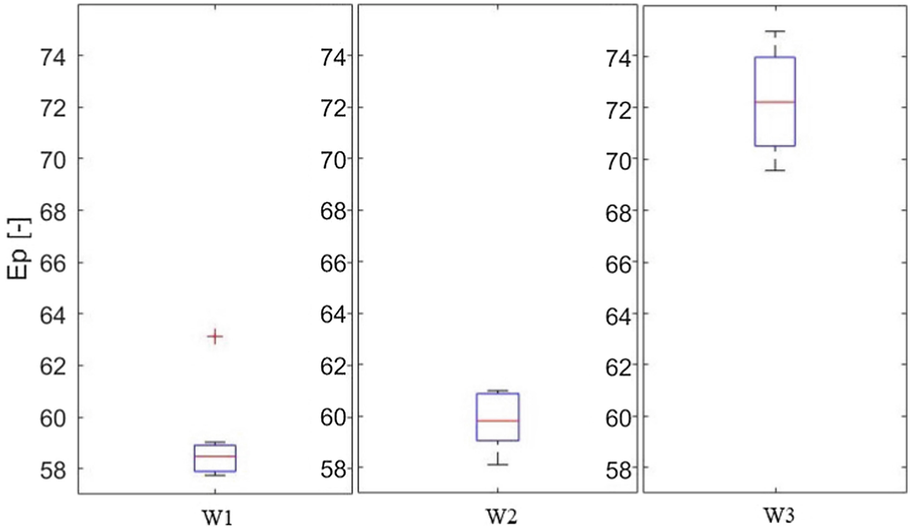

Fig. 2. Box plot for variants (a) w1; (b) w2; (c) w3

The most favourable variant of the solutions included in the analysis in the view of the selected environmental indicators and weighting is the concrete surface with cement-stabilised soil substructure (W1). The average Ep value in this option was 59. A comparable solution is the W2 variant (substructure made of crush-stone aggregate) for which the average Ep value is only 0.8 less. Typical variation ranges of W1 and W2 variant overlap, despite the small variation of coefficient W2 of 1.96%. So there is a collection of solutions in the W2 variant, which are characterised by lower impact on the environment - depending on the material supplier. The variant of substructure made of lean concrete (W3), is clearly a solution worse than the others. None of the analysed suppliers offered a competitive material in terms of environmental conditions, despite the largest coefficient of evaluation variation (3.17%).

The share of environmental categories in the evaluation structure also varies within the variants (Fig. 3). Therefore, the evaluation result will be sensitive to the weights of the evaluation indicators and therefore depends on the adopted methodology of weighing and the range of impact (other weights are adopted in local considerations that take into account the local environmental problems, and other for the global considerations).

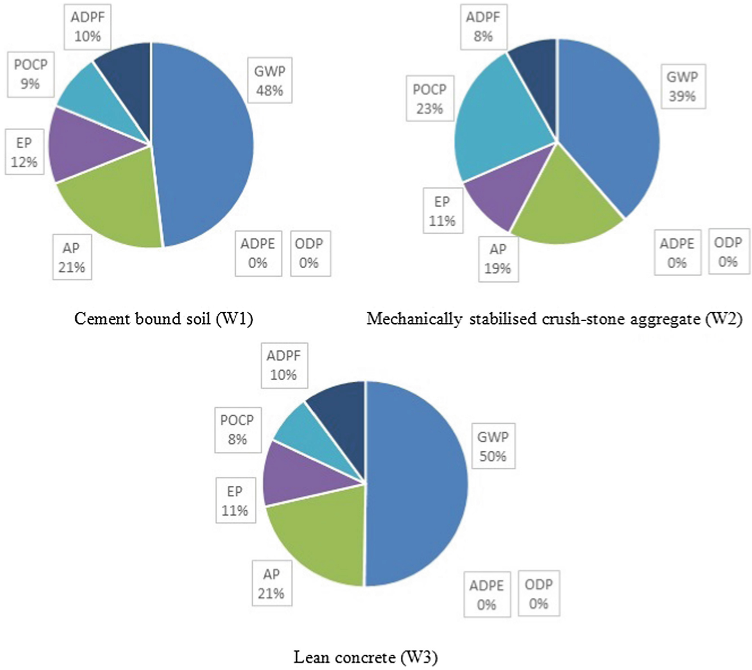

Fig. 3. Share of the environmental impacts in the evaluation structure

4 Conclusions

The evaluation enabled the prioritisation of concrete roads construction solutions from the point of view of environmental impact. Adopting the average value as the variant evaluation measure, the best solution is a substructure respectively made of cement-stabilised soil, crush-stone aggregate and the lean concrete. The obtained measurements may be a part of the sustainable evaluation for the road investment projects. The analyses show that the adopted methodology of weighing the environmental indicators can significantly affect the evaluation results Furthermore obtained results for the adopted methodology are not timeless - the change the current state of the environment and its impact on the ecosystem can result in a change in the environmental criteria weights in time and thus stimulate the evaluation result. A similar approach to environmental impact assessment is observed in other branches of industry. In the works [14, 15] LCA and multi-criteria analysis were also used using various methods. The process of integrated design now enters the engineering practice, which requires additional efforts to conduct associated analyses and studies. The evaluation of the impact on the environment is a complex and interdisciplinary process. It requires close cooperation of the design engineer and the environmental engineer or learning the additional methods and tools for the determination of the environmental impact indicators by the designer. The necessity to obtain information about the implications of the individual technological processes on the environment is also a problem - they are not widely available. Nevertheless, the workload allows for a complete evaluation of the selected material-construction solutions.

A favourable approach to design is the differentiation of material solutions and calculation of the overall impact of e.g. a planned road based on the knowledge of the material environmental profile and the characteristics of its use. In the course of further study it is planned to extend the number of variants for the concrete pavements involved in the assessment and the extension of the evaluation by successive stages of the life cycle of the structure.

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