

MATERIAL SOLUTIONS FOR BIKE AND PEDESTRIAN TRACKS IN A CONTEXT OF ENVIRONMENT PROTECTION

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ABSTRACT

Pedestrian and bicycle traffic becomes a subject of numerous urban, technical, social, economical and medical studies. The paper presents some material solutions for pavement of pedestrian and bike tracks in the context of their use as transport and recreation means. Service properties of pavement as durability, safety, comfort and aesthetics were considered. Examples of ecological pavement types were characterised. Questionnaire survey among potential users of pedestrian and bike tracks was carried out in order to know the opinions on currently existing tracks and expectations regarding planned tracks. Also some in-situ experiments were carried out for five districts in the city of Poznań in Poland to assess the current state and material solutions of selected tracks. The research confirmed the increasing social interest, especially in the use of bike tracks, which indicates the deepening pro-ecological awareness and is a chance to improve the condition and health of users simultaneously partly reducing pollution and noise burden of motoring on the environment.

Key words: pedestrian track, bike track, pavement, material solution, environment

INTRODUCTION

Achievements of new technics and technologies including cement industry and concrete manufacture on the one hand are benefits but on the other have negative impact on natural environment. Contamination of water and soil, pollution of air with greenhouse gases, e.g. carbon dioxide are evident. The latter, staying in agreement with anthropogenic theory, leads to global warming. The crucial contributor to world carbon dioxide emission is manufacture of Portland cement. At least 5–7% of carbon dioxide released to atmosphere is just due to cement industry (Nazari & Sanjayan, 2017).

Human beings are unable to give up progress but they have to do our best to keep balance between pillars of sustainability: environment, economy and soci-

ety. Fortunately, social consciousness is growing and it refers to different areas of life. Pedestrian and bicycle traffic is one of them. Besides advantages related to health due to an increased physical activity, they have a good effect on climate in cities making them more friendly for citizens and tourists.

Pedestrian and bike traffic is well appreciated in the cities worldwide, which encourage citizens to this type of activity. Copenhagen is a perfect example of a city supporting transport means different than cars. Environment-friendly investments in the capital of Denmark became its landmark and the city is called the city of bikers (Radzinski, 2012). The Dutch handbook for bicycle infrastructure planning “Design manual for bicycle traffic” published in 2007 specifies five criteria for bike tracks planning: consistency, directness, comfort, safety and attractiveness (Beim, 2012).

“Pedestrian planning and design guide” issued in 2009 by New Zealand Transport Agency relates to rules of design for pedestrian pavement using proper materials (Beim, Rakower & Rychlewski, 2006). Polish law documents including reference to the pedestrian and bicycle traffic are not satisfactory enough yet, because they fail to include modern scientific and practical achievements.

Pedestrian and bike track pavements are designed as monolithic or from module elements. The most popular continuous ones are made of asphalt, concrete, resin or chemically hardening masses and soil. The most popular separate components used for pedestrian and bike tracks are concrete blocks, granite blocks and concrete slabs (Maliński, 2014).

Asphalt, the most frequently used material to construct continuous pavements of pedestrian and bike tracks, can be used as an asphalt concrete, stone mastic asphalt and porous asphalt. The latter is an example of “silent” pavement (Gardziejczyk, 2014). Moreover, it ensures a better permeability for water drainage to the interior of wear layer and further to the road side. Such a pavement improves the driving comfort by reduction of reflection from the surface (Maliński, 2014). Wear layers frequently contain foamed asphalt, which is formed by binding the granulated aggregate by hot, foamed binder. The foamed asphalt does not require high quality aggregate, shrinkage cracks are not formed in it. Asphalt pavement can be prepared as warm mix (WMA – warm-mix asphalt) or hot mix (HMA – hot-mix asphalt). Warm mix is more economical and more environment-friendly for lower energy use during production. However, such mix has to be enriched with agents reducing viscosity, which increase the moisture content. Also the aggregate for WMA has a larger moisture content than HMA. Thus, there is a challenge for the material chemistry to find a compromise between the ecological and technical goals (Medeiros, Daniel, Bolton & Meagher, 2012). Sweden – the country with a very environment-friendly policies, suggests the need to undertake any possible actions leading to reduction of cost and carbon dioxide emission to the atmosphere. The use of electric energy in production as well as enhancing of additives and admixtures to asphalt mixes is suggested (Butt, Mirzadeh, Toller & Borgisson, 2014).

More and more elaborated solutions for pedestrian track pavements are prepared in the highly developed countries. One excellent example is the so called elastic pavement. It features asphalt layers reinforced with glass fibre in the form of meshes between the base and wear course (Gedafa, Hossain, Miller & Van, 2014).

Rubber modified asphalt is more frequently used in road construction. The rubber granulate included in such a mix is usually obtained from worn car tyres. Mixes with rubber are more resistant to plastic deformation and cracking and have higher softening temperature. Additionally, they ensure a better grip of car tyres and lower noise emission (Szydło, Koba & Skotnicki, 2010; Radzimski, 2012).

Another aspect of proecological attitude to production of asphalt mixes is recycling of bitumen materials from demolition of worn road pavement. This material is ground and contents separated (bitumen from aggregate). Such a solution not only allows the recycling of waste but also saves energy (Radziszewski, Kowalski, Sarnowski & Pokorski, 2014).

Thin wear courses made from fine aggregate mix also features good acoustic properties. They are more durable than the porous asphalt and, moreover, the dirt deposit does not deteriorate the noise reduction properties. Another type of silent pavement is the modular one developed in Holland. It consists of two-layered concrete slabs with a drainage system. Such means of noise reduction may prove a successful alternative for non-aesthetic noise barriers (Baptista, Picado-Santos & Capita, 2013).

Cast concrete including a coloured option is a competitive solution from the point of view of durability, deformation resistance and aesthetics for pedestrian and bike track pavements (Bańkowski & Sybilski, 2009).

Besides the concrete roads made as cast concrete, the roller-compacted concrete becomes more and more popular recently. It is similarly effective to produce as the asphalt pavement. It ensures high quality, durability and is economically attractive. However, it is difficult to ensure an even surface (Woyciechowski & Harat, 2012).

According to Jackiewicz-Rek and Konopska-Piechurska (2012), concrete pavement becomes more and more attractive due to better properties, when com-

pared to asphalt one. It is the case of higher durability, smaller susceptibility to deformation and rutting leading to a better comfort and safety. Industrial waste can be used to produce concrete pavement. Surely, “green” concrete technology is recommended including use both eco-cements and industrial waste. In the first case carbon dioxide emission is reduced, in the second, a problem of deposit of such substances can be addressed and savings on natural resources can be made. A brighter surface of concrete pavement which is possible to create due to use e.g. blast furnace slag cement reduces the amount of electric energy applied for illumination and also reduces the phenomenon of the so called “city heat island” (Błażejczyk et al., 2014).

A solution characteristic for tourist tracks in forest area, including the natural reserve zones, is a beaten track made from densified aggregate laid on natural stabilised soil. It is characterised by a low cost and quick production. Soil tracks fit the rural landscape and they do not interfere with environment. However, they are vulnerable to adverse weather conditions, action of plants and animals. A good alternative is a mineral pavement stabilised by plant-based means. Such a pavement is permeable, environment-friendly, aesthetic and fits well the landscape (Radziszewski et al., 2014).

Wood is a material which, without any doubt, fits the landscape in the case of touristic pedestrian and bike tracks (bridges) (Kotaskova & Hruza, 2013). Nowadays glued wood laminates are preferred over the natural wood (Vaskova, Fojtik & Pustka, 2016).

In the summary, a rational choice of technology and material for pedestrian and bike tracks can reduce disadvantages of the road construction process and ensure the environmental safety in zones with valuable natural resources. Among the proposed material solutions for pavements, the most environment-friendly are, according to the authors of this paper, asphalt pavements of new generations and in some cases these are surfaces made of “green concrete”.

EXPERIMENTAL PROCEDURE

Questionnaire survey analysis and own in-situ survey in selected zones in the city of Poznań were carried out.

Poznań – the capital of Great Poland Voivodship is located in the central part of the voivodship on river Warta. The municipal area is 261.9 km² and is divided into five administration districts. The area is highly urbanized with about 48% of it being built-up or serving for transport. The built-up zones are located between park areas forming a wedge-ring system. The park zones include the natural river valleys (Warta, Bogdanka and Cybina) piercing the city centre from four directions: north-south, east-west. Additionally, the valleys of Junikowo Stream and Głuszynka form the wedges in the south-west direction. The specific layout of park zones is aimed at protection of water and air resources as well as at providing the citizens with attractive recreation zones.

The anonymous survey took place among various groups of potential users of pedestrian and bike tracks. The gathered answers were subjected to a statistical analysis in order to determine relations between the respondents profile and their preferences and expectations regarding the pavement of pedestrian and bike tracks as well as to indicate the most optimal material solutions according to the respondents. Examination of users’ opinions (670) and preferences was carried out as a direct interview and using an internet questionnaire. The questionnaire contained two forms – one related to pedestrian walks, another – to bike tracks. There were multiple choice questions and questions, where the opinion was expressed using a five grade scale with ‘1’ as the lowest grade and ‘5’ as the highest one. The scale questions regarded assessment of quality and technical state of pedestrian and bike tracks as well as the degree in which the type of the used pavement influences the general assessment of pedestrian and bicycle infrastructure.

Multiple choice questions were used to collect opinions on the most important properties of the tracks pavement and the correctness of combining the pedestrian and bike tracks into common tracks. In the case of the most important properties, the choice was between safety, aesthetics and durability. In the case of bike tracks this range was expanded with the riding comfort. Due to the different nature of pedestrian and bike traffic, questionnaires contained different questions related to these two tracks types. In the case of bike tracks, questions concerned the frequency of rid-

ing and the main purpose of riding (recreation, commuting, others). In the analysis of pedestrian walks, the question regarding the frequency did not seem appropriate because every time one leaves home – he uses pedestrian tracks. Thus, a question was focused on the frequency of recreational use of pedestrian tracks with the assumption to obtain more differentiated and less obvious answers. Besides, the users of pedestrian walks answered the question, if they paid any attention to the pavement type. The users of bike tracks were asked to indicate the most comfortable type of pavement – the choice was to be made between asphalt, continuous concrete, stone and soil roads.

The results of survey were analysed statistically and they were visualised. Microsoft Excel 2007 spreadsheets and test version of Statistica 12 package were used. The opinions gathered in the survey can be related to the current state met during the in-situ survey on the existing pavement material solutions.

The in-situ survey consisted of visual assessment of the pavement state and materials used in the existing pedestrian and bike tracks. Photographic documentation (334 photos) was made using a camera with GPS system built in. Selected photos with the localisation were put onto a bike map opencyclemap.com, and results posters presenting the tracks state in subsequent zones were prepared using the program Quantum GIS.

The selected districts of the city of Poznań for the in-situ survey were subdivided into three categories differing with the land management and type of buildings. Category I related to the city centre with Old Town. From the point of view of the analysed problem, existence of various types of pavement in pedestrian and bike tracks in this area is a very important issue. Besides, this zone features densely build-up areas, many buildings possess service function. There is a little amount of green areas and presence of limited traffic or closed-for-car zones. Category II included residential districts Piątkowo and Rataje. They feature mainly the prefabricated large-slab multi-flat buildings. Here, the important aspect is the presence of service buildings in the form of commercial centres. It is important to note, that the main bike track axis of the city passes through Piątkowo – Centre – Rataje. Category III included the most popular recreation

zones: Cytadela and Malta. The study of conditions and directions of urban development of City of Poznań issued in 2014 indicates that Malta is crossed not only by pedestrian and bike tracks with recreation-touristic character but also by the all-city historic track – Royal-Imperial Route.

RESULTS AND DISCUSSION

Questionnaire survey

Respondents characteristics

The majority of respondents (61.0%) are 25 years old and younger, with almost twice as many women than men. The domination of young people below the age of 25 can result from the method of survey – only 53 questionnaires were filled traditionally – the remaining 617 were achieved via internet, using the form included among others in internet forums related to biking.

From the point of view of the structure of respondents residence, the largest groups are: persons below 25 years of age living in the cities over 100 thousand inhabitants (164 persons), those between 26 and 39 living in the cities over 100 thousand inhabitants (125 persons) and 25 years old and younger living in villages (119 persons).

Over the half of respondents (50.2%) are pupils or students, the second most populated group are employees (39.1%).

Analysis of opinions and preferences of pedestrian tracks users

The first scale question concerned the assessment of quality and technical state of pedestrian tracks. The users' level of satisfaction from the quality and state of the tracks is intermediate. The mean mark given was '3.11'. Almost a quarter of respondents is not satisfied – 16.6% assessed it as bad and 7.8% – as very bad. In the analysis of state and quality assessment for pedestrian tracks including the sex criterion one can note that women are more critical, almost one third of female respondents gave negative mark (bad 19.7%, very bad 9.6%). The residence has an essential influence on the assessment of quality and state of pedestrian tracks. The largest differences occur in the case of answers

from respondents living in cities over 100 thousand inhabitants and those living in villages. As many as 37.9% of village inhabitants assesses the quality in a negative way (very bad 14.2%, bad 23.7%). Among the inhabitants of cities over 100 thousand inhabitants, the negative assessment was given by 19.5% of respondents (very bad 5.8%, bad 13.6%). In those cities the percentage of positive assessments was highest (very good 6.5%, good 37.7%).

One of the questions in the survey was aimed at determining the influence of pavement type on the general opinion on a pedestrian track. The mean result ('3.8' in five-point scale) of this influence on the general opinion on pedestrian infrastructure indicates that the pavement type is important.

The respondents were also asked to specify the most important feature of the pedestrian tracks with the choice to be made between: durability, aesthetics and safety. The latter was considered as the most important – such an answer was selected by as many as 71.2% of the respondents. Durability ranked second with 19.0% votes. Aesthetics turned out to be the least important feature – only 9.8% of the respondents consider it as most important. In the analysis of the answers when taking into account respondents' sex one can note, that as many as 77.8% of women appreciate the pavement safety. Among men 61.0% voted for safety. Durabil-

ity had the largest percentage among 25 years old and younger respondents (21.0%), whereas aesthetics – among 26 to 39 years old ones (11.8%).

In the summary of the pedestrian tracks survey, one should note that the level of satisfaction with their quality and technical state among users is intermediate. The most demanding persons are women and those of 40 years old and older. The majority of respondents admitted, that they pay special attention to the tracks pavement and the most important feature for them is safety. Higher requirements in the group of 40 years old and elder may result from mobility difficulties among elderly people. Those problems with transit increase when pedestrian tracks are of bad quality with pavement in a poor technical state.

Analysis of opinions and preferences among bike tracks users

Two of the important questions regard the frequency and the main purpose of the bike track use. A 3D graph was created in the program *Statistica* to quantitatively present differences between the respondents' answers in order to analyse the mentioned above relations (Fig. 1). Horizontal axis denotes the question on the biking frequency, vertical – that on the main purpose of the bike tracks use. As is indicated in the graph, persons riding a bike everyday use the tracks mainly

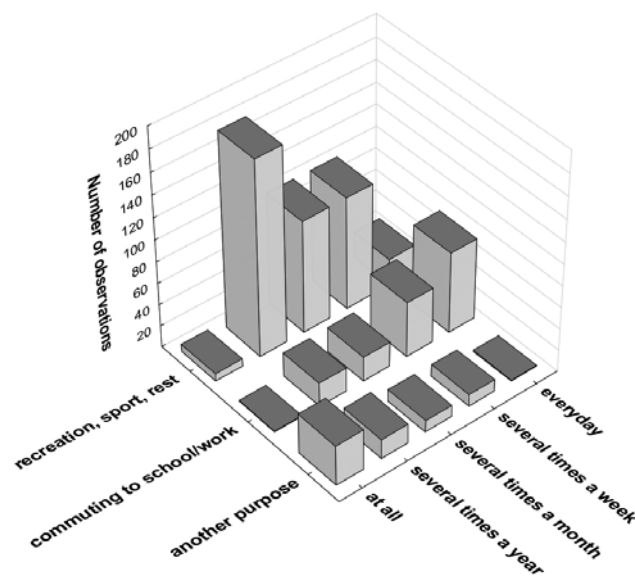


Fig. 1. Relation between biking frequency and the main purpose of bike tracks use

to commute to school or work. The persons using the bike tracks mainly for recreation do so several times a year, several times a month or several times a week.

Similarly as in the case of pedestrian tracks survey, the bike tracks users were asked to assess the state and quality of bike infrastructure in the neighbourhood. The mean mark reached was '2.89'. Thus the respondents were a little bit less satisfied with the bike tracks state, than those assessing the pedestrian tracks (who gave the mean mark '3.11'). The most critical age group proved to be that with 40 years old and elder. The residence place of respondents has a significant influence on the state and quality assessment for the bike infrastructure. The largest differences are observed between those living in cities between 50 and 100 thousand inhabitants and village residents. Almost one half of village inhabitants assessed the bike tracks quality negatively (very bad 21.3%, bad 28.4%), whereas only 17.2% – positively (very good 4.7%, good 12.4%).

Among the bike traffic society continuous discussions are held on the subject of appropriate bike track pavements. This problem was addressed in the bike survey, too. The respondents were asked to indicate the most comfortable pavement type. The vast majority (80.5%) chose asphalt. The remaining accepted pavement types were: continuous concrete – 9.2%, stone aggregate – 5.1%, concrete blocks – 2.8% and soil – 2.4%.

As was with the pedestrian tracks, the users of bike tracks were asked to choose the most important feature of the track. The choice was between safety, riding comfort, aesthetics and durability. For the overall number of respondents safety of bike tracks was the most important feature – such an answer was given by 46.9%. Riding comfort ranked just a little lower with 44.9%. Third place was for durability with 7.3% of votes. Aesthetics proved to be the least popular factor – only 0.9% of respondents indicated it as the most important.

In the summary, the bike tracks users are intermediately satisfied with their quality and technical state. Village residents presented the least positive opinions on this subject – it is related to the little level of bike tracks network development in rural areas. Investment in bike infrastructure is characteristic for cities, where a bike is frequently an alternative for a car. In the problem of most comfortable pavement type, asphalt is

considered as best by the vast majority of respondents. Despite the fact, that continuous concrete pavement exhibits similar level of riding comfort, only 9.2% of respondents chose that material as most comfortable. This small number of votes results form a small popularity of this material solution for bike tracks in Poland. Polish bike users are not aware of many advantages of this material. The respondents indicated safety and riding comfort as most important. It is worth noting that these are the properties of both material solutions: asphalt and continuous concrete.

In-situ survey

State of pedestrian and bike tracks

Category I (City Centre and Old Town). The state of pedestrian and bike tracks in this zone, featuring a very high variation of pavement types, can be assessed as satisfactory. However, in some places damage is found (cracked or uneven pavement slabs, with casual repair type (Fig. 2). The positively assessed pedestrian track pavements are made from various materials (stone blocks or slabs, concrete pavement blocks), frequently with different hues or even colour, what, in the case of natural stone materials, interacts with historical and representative character of this district (Fig. 3), positively influences the city outlook as well as comfort and safety of use.

There are few separated bike tracks in the Old Town district, thus the bike traffic is allowed unchamfered concrete blocks. This is the reason for a small comfort of use but such a situation is acceptable in the districts subjected to conservation protection and the pavement of this type fits well the neighbouring pavement made of natural stone (Fig. 4).

Category II (Piątkowo and Rataje). In the districts of multi-flat block-of-flats buildings pavement of various concrete blocks are dominant (Fig. 5). The amount of pedestrian tracks made of asphalt concrete is large, especially in Piątkowo. The largest variation of pedestrian tracks pavement (granite bricks, concrete blocks with various shapes and colour, asphalt concrete) is found in the detached house areas (Fig. 6), especially in Piątkowo, because in Rataje district such areas do not exist.



Fig. 2. Pavement state in Grochowe Łąki Street (photo by S. Kurpisz)



Fig. 3. Material solution for pavement around Old Market Place (photo by S. Kurpisz)



Fig. 4. Counterflow along Za Bramką Street (photo by S. Kurpisz)



Fig. 5. Concrete blocks pavement in Bolesław Chrobry district (photo by S. Kurpisz)



Fig. 6. Various pavement types of pedestrian tracks between the detached houses in Piątkowo (photo by S. Kurpisz)

The pavement state in Rataje district is better than in Piątkowo. It is a result of exchange of pedestrian tracks pavement and a more rational choice of materials for new bike tracks.

Category III (Cytadela and Malta). The significant part of these zones is a recreation area with a high level of material variations for pavement in Cytadela. The majority of tracks in Cytadela Park has an asphalt concrete pavement, in some cases requiring renovation. Concrete and stone slabs are used, too. When suitably

incorporated into the park landscape, they are highly decorative (Fig. 7). There are also numerous tracks with gravel and soil pavement in the Park, which fit the park landscape and are environment-friendly, too, due to their permeability (Fig. 8).

The pedestrian-bike route around the Malta Lake is mostly built from asphalt concrete (Fig. 9). Only few side access routes or squares are made from concrete slabs (Fig. 10) or concrete blocks (Fig. 11). Pedestrian and bike traffic along the southern bank of the lake are separated. However, both tracks are made from



Fig. 7. Decorative stone and concrete slabs in Cytadela Park (photo by S. Kurpisz)



Fig. 8. Gravel pavement in Cytadela Park (photo by S. Kurpisz)



Fig. 9. Asphalt concrete pavement of pedestrian-bike track in Malta (photo by S. Kurpisz)



Fig. 10. Concrete slab pavement of pedestrian-bike track in Malta (photo by S. Kurpisz)



Fig. 11. Concrete blocks pavement of pedestrian-bike track in Malta (photo by S. Kurpisz)

asphalt concrete. A pedestrian-bike asphalt route along the northern bank features a very intensive traffic, especially in spring–summer time. The technical state of pedestrian and bike tracks around Malta is very good.

CONCLUSIONS

Based on the literature and own studies, the following conclusions were formulated:

- Safety is the most important factor for pedestrian tracks users, whereas for the bike tracks ones – safety and riding comfort prevail.
- Asphalt is perceived as the most comfortable pavement type according to preferences of bike track users.
- The property of pavement underestimated by both pedestrians and bikers is its durability.
- In selected analysed districts of the city of Poznań, aimed at assessment of material solutions for existing pedestrians and bike tracks a large variety is exhibited in the city centre and Old Town, whereas a smaller variation exists in Piątkowo, Rataje, Cytadela and Malta.
- The pavement state of bike tracks in the majority of analysed cases can be assessed as satisfactory.
- For lower collision risk counterflows for bikes in the street lanes are better solution in comparison to merging of pedestrian and bike routes.
- In the design of bike tracks chamfered concrete blocks should be replaced with unchamfered ones or by continuous concrete.

- Technical knowledge of material solutions for bike and pedestrian tracks should be popularised among average users.
- The increasing significant social interest, especially in the use of bike tracks, indicates the deepening pro-ecological consciousness and seems to be a chance to improve simultaneously reducing pollution and noise burden of motoring on the environment.

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ROZWIĄZANIA MATERIAŁOWE NAWIERZCHNI DRÓG PIESZYCH I ROWEROWYCH W KONTEKŚCIE DZIAŁAŃ PROŚRODOWISKOWYCH

STRESZCZENIE

Ruch pieszy i rowerowy jest tematem licznych badań urbanistycznych, społecznych, ekonomicznych i medycznych. W pracy przedstawiono rozwiązania materiałowe nawierzchni dróg pieszych i rowerowych w kontekście ich użytkowania jako szlaków komunikacyjnych i rekreacyjnych. W analizie rozwiązań uwzględniono cechy użytkowe nawierzchni, takie jak: trwałość, bezpieczeństwo, komfort użytkowania i estetyka. Przeprowadzono badania ankietowe wśród potencjalnych użytkowników dróg pieszych i rowerowych w celu poznania opinii na temat istniejących dróg i oczekiwań wobec planowanych oraz badania terenowe obejmujące pięć jednostek obszarowych miasta Poznania, mające na celu ocenę aktualnego stanu i rozwiązań materiałowych nawierzchni wybranych dróg pieszych i rowerowych. Badania potwierdziły wzrastające zainteresowanie społeczne, zwłaszcza użytkowaniem dróg rowerowych, co świadczy o pogłębianiu się świadomości proekologicznej, dzięki czemu zwiększa się szansa na poprawę kondycji i zdrowia użytkowników oraz na częściowe odciążenie środowiska od zanieczyszczeń i hałasu, jakie niesie motoryzacja.

Słowa kluczowe: droga piesza, droga rowerowa, nawierzchnia, rozwiązanie materiałowe, środowisko