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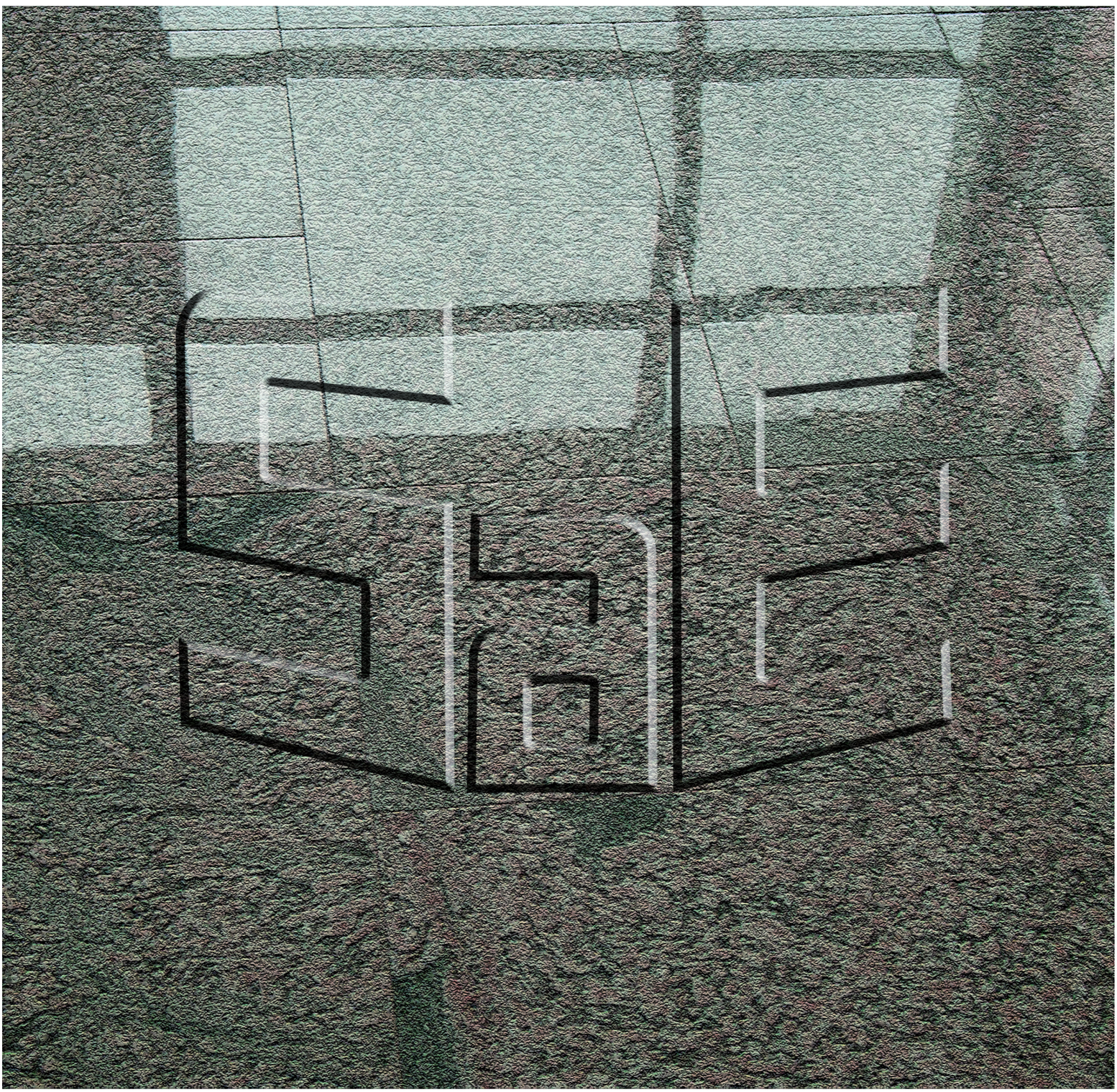

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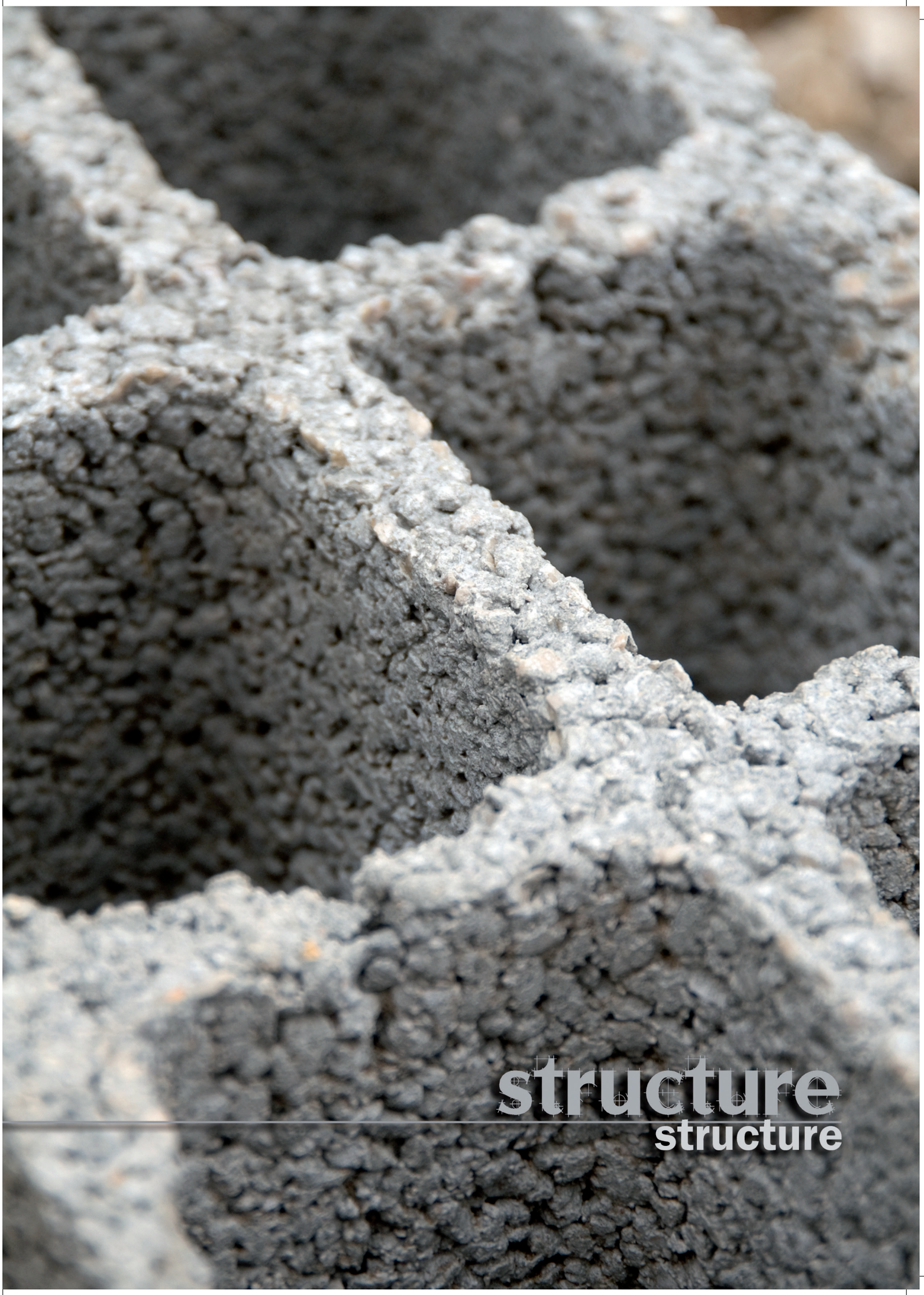

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CLASSIFICATION OF SETTLEMENTS BY ECONOMIC POTENTIALS IN THE SOUTHERN REGION OF NIGER STATE: A LOCATION QUOTIENT APPROACH

KLASYFIKACJA OSAD WEDŁUG POTENCJAŁU GOSPODARCZEGO W POŁUDNIOWYM REGIONIE STANU NIGER (W NIGERII): PODEJŚCIE OPARTE NA ILORAZIE LOKALIZACJI

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Abstract

Regional economic activities and developments are measured through various techniques where Location Quotient (LQ) is one of the most reliable techniques. This paper classifies the settlements by economic potentials in the southern region of Niger state using the LQ. A structured questionnaire was administered to 1.040 in the 37 rural communities selected from 37 districts in 8 LGAs in the Niger South Federal constituency in Niger State. The data collected was analysed using LQ. Findings of the study in terms of economic potentials of the region, reveals that communities are mainly engaged in basic economic activities; including the cultivation of food crops (rice, maize, beans, millet and yam); cultivation of cash crops (benisead, ground nut, vegetable, cassava and melon), plantation agriculture (palm, kola nut, cashew and sugar cane). Findings in terms of basic economy revealed that Egbako has the highest LQ with an average score of 0.06, and is closely followed by Takuma, Batako, Kusoyaba, Mukugi and Kalmo, with an average LQ score of 0.04 each, while in terms of non-basic economy, the findings indicates that both Egbako and Kuchita have the highest non-basic LQ with an average score of 0.07, which were closely followed by Katcha, Mukugi and Gayankpa settlements with non-basic economic LQ and average scores of 0.04 each. The study concludes that LQ is one of the best techniques in measuring economic potentials of regions. It also recommends LQ for regional economic assessments.

Keywords: economic potentials, Location Quotient, Settlement classification, Regional planning, Southern region of Niger State

Streszczenie

Działalność gospodarcza w regionie oraz rozwój regionu są mierzone różnymi metodami, wśród których iloraz lokalizacji (LQ) jest jedną z najbardziej wiarygodnych technik. Niniejszy artykuł klasyfikuje osady według potencjału gospodarczego w południowym regionie stanu Niger przy użyciu wskaźnika specjalizacji regionalnej LQ. Ankietę zawierającą pytania zamknięte rozdano 1040 osobom w 37 społecznościach wiejskich wybranych z 37 stref ośmiu obszarów samorządowych w okręgu federalnym Niger South w stanie Niger. Zebrane dane zostały przeanalizowane przy użyciu techniki LQ. Wyniki badania w zakresie potencjału gospodarczego regionu pokazują, że społeczności są głównie zaangażowane w bazową działalność gospodarczą, w tym uprawę roślin spożywczych (ryż, kukurydza, fasola, proso i ignam); produkcję upraw rynkowych (benisead, orzeszki ziemne, warzywa, maniok i melony), rolnictwo plantacyjne (palma, orzech kola, nerkowiec i trzcina cukrowa). Najwyższą wartość LQ dla działalności podstawowej uzyskało Egbako ze średnim wynikiem 0,06,

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następnie Takuma, Batako, Kusoyaba, Mukugi i Kalmo, ze średnim wynikiem LQ 0,04. Pod względem gospodarki niebazowej zarówno Egbako, jak i Kuchita mają najwyższe LQ ze średnim wynikiem 0,07, a tuż za nimi plasują się osady Katcha, Mukugi i Gayankpa ze średnimi wynikami LQ 0,04. W badaniach stwierdzono, że LQ jest jedną z najlepszych technik pomiaru potencjału gospodarczego regionów. Technikę tę poleca się również do wykorzystania przy sporządzaniu ekonomicznych ocen regionalnych.

Słowa kluczowe: potencjał ekonomiczny, iloraz lokalizacji, klasyfikacja osad, planowanie regionalne, południowy region stanu Niger

1. INTRODUCTION

Globally, the economic developments of regions are responsible for the livelihood and wellbeing of the people (Wang et al., 2011; Hilson, 2016; Liu & Liu, 2016). The regional economic sectors are grouped into basic and non-basic (Thulin, 2015). The regional basic economic sector is the most contributing sector of the economy, while the non-basic regional economic sector contributes less compared to the overall regional economy (Thulin, 2015; Becker, 2017; Flath, 2022). The economic planners use several equations and methods which significantly benefit the economy and its activities at the national, regional and local levels. In addition, Planners are extracting figures that give important economic implications based on which the direction is use those figures analysis in the economic support (Alhowaish et al., 2015).

There are several factors affecting the regional economic potentials and developments (Reznichenko, et al., 2018), which includes low level of modern skills and technology (Zheng et al., 2019), climate variability (Malhi et al., 2021), poor infrastructure (Kanwal et al., 2020), epidemic (Gong et al., 2020), and floods and other forms of disaster (Hino et al., 2019), among others. This has attracted researches on the regional economic assessments. However, far less attention is usually paid to the processes of local and regional economic development within countries, and to a large extent, the macro-regional production configurations (Coe & Yeung, 2015).

The regional economic activities and developments are measured through various techniques (Capello & Nijkamp, 2019; Elia et al., 2017; Capello, 2015), where Location Quotient (LQ) is one of the most reliable techniques (Alhowaish et al., 2015; Prats, 2018). LQ is the ratio that provides a convenient way to examine the specialization of economic activity in a region (Tabassum et al., 2015). For example, LQ was adopted by Harjanti et al. (2021) to describe the pattern of changes in economic growth and determine the potential sectors in Sanggau Regency, West Kalimantan, Indonesia. It was also adopted by Kartikawati and Sundari (2019) in examining the role of agriculture, forestry and fishery sectors in the development of Malinau District, North Kalimantan Province, Indonesia. Morrissey (2016) assesses the regional production multipliers for the Irish economy using the LQ. Islam et al. (2016) also determines economic growth of six divisions of Bangladesh using the LQ. These researches clearly established the relevance and importance of LQ in assessing regional economic potentials and developments.

In Nigeria, the LQ was applied in examining infrastructure and spatial concentration of cattle in Wudil market (Gambo, 2020), spatial concentration of traders in specialized agricultural food-products markets of Kano metropolis (Gambo, 2017), social infrastructure (Anthonia et al., 2018), regional inequalities in socio-economic development in Nassarawa State (Adefila, 2013), among others. However, less attention has been paid to the economic potentials and development of flood communities of river Niger valley in Nigeria. Although, Bukka, et al. (2017) while analysing the regional floods of Muwo district, Mokwa, Niger State, opined that the effects of flooding on the livelihood of rural communities has a significant increase in the loss of agricultural produce with increasing individual farm size during flood events, though, the study uses descriptive statistics and was restricted only to Muwo district out of the 39 districts in the study area. With more regional assessment of flood prone communities and application of LQ in the assessment of economic potentials, this is yet a gap needed to fill in the literature. As such this paper classifies the settlements by economic potentials in the southern region of Niger state using the LQ.

2. METHODOLOGY

Study area

The study area is located between latitudes 8°20'N and 9°45'N and longitudes 4°85'E and 6°80'E. It is an extensive lowland region with about 100-200 metres in height covering eight Local Government Areas of Mokwa, Edati, Lavun, Katcha, Agaie, Bida, Gbako and Lapai, respectively (see Figures 1 and 2).

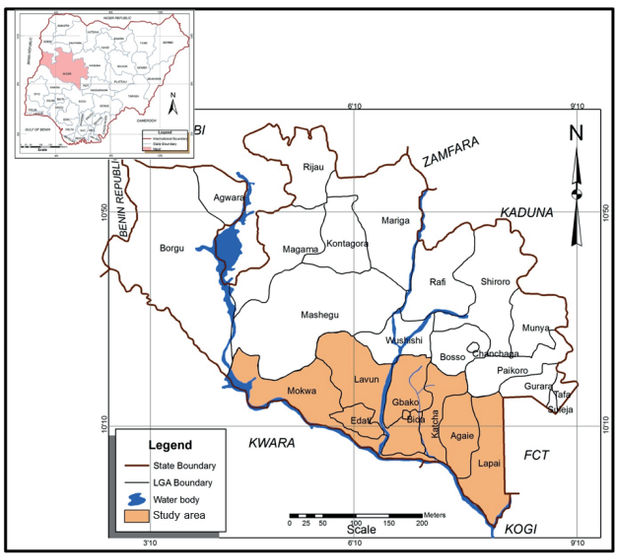

Fig. 1. Location of the Study Area in Niger State, Nigeria
Source: Niger Ministry of Lands and Housing, 2017.

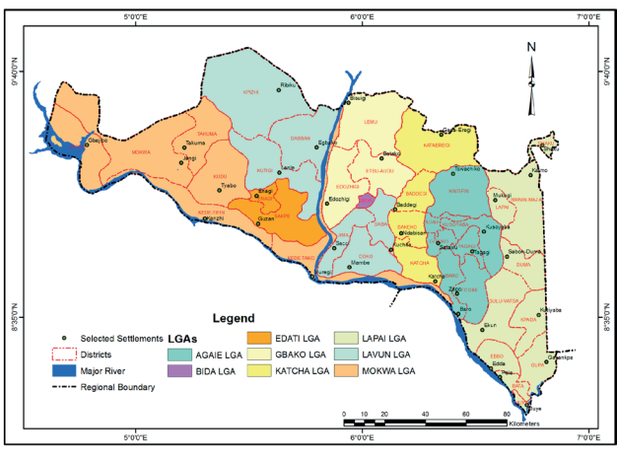

Fig. 2. Sample frame
Source: Field survey, 2020.

The area has an abundant water resources, and the major river is the Niger, called Ndaduma in Nupe. The name Niger was given to the River by the Europeans, and it originated from the Futa Jallon highlands of Guinea. The river passed through different areas in West Africa including Nupe land which it entered around Leaba, covering its full length down to Muye area in Lapai Local Government. The river provides a large population of the Nupe people with their means of livelihood (Mohammed, 2011). Apart from the fishing and Canoe transportation done on the river, it is known to be a carrier of alluvium from its upper course, down to Nupe land and beyond which is deposited on its flood plains, making the plains fertile and suitable for extensive rice cultivation along the valley from Jebba to Muye (Mohammed, 2011). Similar situation applies to the flood plains of other rivers in the area, many of which are tributaries of the Niger on its Eastern and Western sides such as Eku and Yampere, Kaduna, Gbako and Gurara rivers, respectively (Afolabi, 1973; Iwena, 2015).

The sample frame is 37 rural communities selected from 37 districts in 8 LGAs in the Niger South Federal constituency in Niger State. The graphical representation of the sample frame is presented in Figure 2.

Data and analysis

A structured questionnaire was administered to 1,040 respondents in the study area. The data collected for this paper includes the basic (farming, fishing and livestock) and non-basic (trades, crafts, hunting and canoe building) economic potentials of the region; the settlement classification based on their respective economic activities/values and land resources evaluation (classification). The data collected were analysed using Location Quotient (LQ). LQ is the ratio that provides a convenient way to examine the specialization of economic activity in a region. LQs can be based on the level of employment, local industries, income or value added data and other variables (Tabassum, Hauque & Debnath, 2015). The general formula of LQ is:

$$\frac{\left[\frac{e_i}{e}\right]}{\left[\frac{E_i}{E}\right]} = \frac{Share\ of\ regional\ economic\ based\ in\ sector\ i}{Share\ of\ national\ economic\ based\ in\ sector\ i} \quad (1)$$

where:

e_i – Regional economic based in sector i,
e – Total regional economic based (all sectors),
E_i – National economic based in sector i,
E – Total national economic based.
In this study, LQ was calculated as:

$$LQ = \frac{\left[\frac{e_i}{e}\right]}{\left[\frac{E_i}{E}\right]} = \frac{Share\ of\ sectoral\ socioeconomic\ activities\ i}{Share\ of\ regional\ socioeconomic\ activities\ i} \quad (2)$$

Therefore, LQ was used to calculate variations in the basic and non-basic economic indicators in the study area.

3. FINDINGS

Location Quotient of Settlements Based on Economic Values

Location Quotient (LQ) which is the ratio that provides a convenient way to examine the specialisation of economic activity in a given region was adopted to analyse the contribution of settlements in terms of basic and non-basic economy to the Niger South region. For the basic economic activities, the aggregated scores of food crops, cash crops, plantation and livestock were summed up to arrive at the total economic score which was used to analyse the LQ. Whereas, the scores of trade, craft, hunting and canoe building were summed up to arrive at the total non-basic economic score which was also used to analyse the non-basic economic LQ of the settlements.

The study revealed in Table 1 that in terms of basic economy, Egbako has the highest LQ with an average score of 0.06, and closely followed by Takuma, Batako, Kusoyaba, Mukugi and Kalmo, with an average LQ score of 0.04 each, respectively. Table 1 further revealed that significant settlements in Niger South, such as Gbajibo, Jangi, Tyabo, Enagi, Guzan, Lanle, Ribiku, Kuchita, Edozhigi, Baddegi, Ndabisan, Tswachiko, Salawu, Tagagi, Shaku and Sabon-Duma have equal average basic economic LQ score of 0.03 each. However, there are some other settlements with an average basic economic LQ score of 0.02 each, including Kanzhi, Sacci, Mambe, Bisuigi, Gada-Eregi, Katcha, Baro, Zago, Kutiyaba, Ekun, Edda and Gayankpa respectively. Settlements with the lowest average basic economic LQ score of 0.01 include; Muregi, Pele and Muye and are all on the River Niger valley. The basic economic LQ indicates specialisation of settlements in agricultural productions/activities in terms of food crops, cash crops and plantation on one hand; and on the other livestock rearing which varies from place to place depending on the location of the settlement in the region.

The analysis in Table 1 further reveals that the scores of trade, craft, hunting and canoe building were summed up to arrive at the total non-basic economic LQ of the settlements in the region. The results of the finding indicates that both Egbako and Kuchita have the highest non-basic economic LQ score of 0.07, and were closely followed by Katcha, Mukugi and Gayankpa settlement with non-basic economic LQ scores of 0.04 each. Other settlements with non-basic economic LQ of 0.03, 0.02 and 0.01 as shown on Table 1 comprehensively.

Table 1. Location Quotient of Basic and Non-basic Economic Potentials in Niger South Region

S/N	Settlements	Basic Economic Mean Score	Basic Economic LQ	Non-Basic Economic Mean Score	Non-Basic Economic LQ
1	Gbajibo	3.63	0.03	0.35	0.02
2	Jangi	4.83	0.03	0.50	0.03
3	Tyabo	4.02	0.03	0.32	0.02
4	Takuma	5.29	0.04	0.29	0.02
5	Kanzhi	2.50	0.02	0.50	0.03
6	Muregi	1.89	0.01	0.33	0.02
7	Enagi	4.16	0.03	0.38	0.03
8	Guzan	4.82	0.03	0.45	0.03
9	Lanle	4.76	0.03	0.41	0.03
10	Egbako	8.00	0.06	1.00	0.07
11	Ribiku	4.67	0.03	0.33	0.02
12	Sacci	2.67	0.02	0.33	0.02
13	Mambe	2.60	0.02	0.40	0.03
14	Kuchita	4.00	0.03	1.00	0.07
15	Edozhigi	3.67	0.03	0.21	0.01
16	Batako	5.00	0.04	0.50	0.03
17	Bisuigi	2.80	0.02	0.40	0.03
18	Gada-Eregi	2.85	0.02	0.30	0.02
19	Baddegi	3.86	0.03	0.26	0.02
20	Ndabisan	4.33	0.03	0.44	0.03
21	Katcha	3.18	0.02	0.55	0.04
22	Tswachiko	4.85	0.03	0.21	0.01
23	Salawu	3.83	0.03	0.33	0.02
24	Kusoyaba	5.31	0.04	0.25	0.02
25	Tagagi	3.68	0.03	0.21	0.01
26	Baro	2.38	0.02	0.28	0.02
27	Zago	3.34	0.02	0.24	0.02
28	Shaku	4.07	0.03	0.43	0.03
29	Mukugi	5.80	0.04	0.60	0.04
30	Kalmo	5.25	0.04	0.25	0.02
31	Sabon-Duma	4.27	0.03	0.33	0.02
32	Kutiyaba	3.33	0.02	0.50	0.03
33	Ekun	2.68	0.02	0.23	0.02
34	Edda	2.67	0.02	0.33	0.02
35	Pele	2.00	0.01	0.33	0.02
36	Muye	1.82	0.01	0.46	0.03
37	Gayankpa	3.04	0.02	0.57	0.04

Source: Field survey, 2020.

Spatial distribution of Basic Economic LQ in the study area is presented in Figure 3. The findings revealed that most of the settlements with high LQ values were located on the Niger valley. However, there are some settlements with lower LQ values in the Niger valley such as Kanzhi, Muregi, Katcha, Zago, Baro, Pele and Muye respectively. This could be as a result of persistent flood incidence in these settlements and also their small nature.

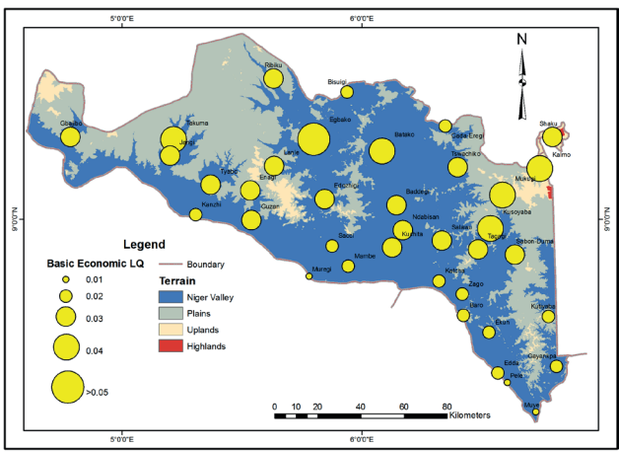

Fig. 3. Spatial Distribution of Basic Economic LQ in the Study Area

Spatial distribution of Non-Basic Economic LQ presented in Figure 4 revealed that high LQ values were found in most settlements in the Niger valley such as Mambe, Katcha and Gayankpa respectively. Although, some smaller settlements in the Niger valley also records small LQ values such as Gbajibo, Muregi, Baro, Edda and Pele respectively. This implies that LQ values across the region depends on the sizes of the settlements.

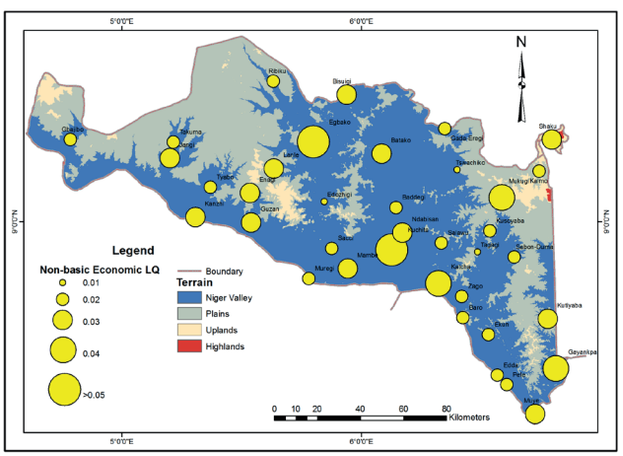

Fig. 4. Spatial Distribution of Non-basic Economic LQ in the Study Area

Settlement Classification Based on Terrain and Location Quotient

Settlements in the Niger State Southern region have earlier been classified into Highlands, Uplands, Plains and Niger Valley respectively. The study in this section investigates LQ of both basic and non-basic economic potentials based on the classified terrains. The study revealed in Table 2 that Egbako which falls in the Plains records highest basic economic LQ. This is followed by five settlements who are located on Niger Valley (Takuma and Batako), Plains (Kusoyaba) and Uplands (Mukugi and Kalmo) recorded 0.04 LQ each. This is an indication that settlements that are located within Niger Valley, Plains, and Uplands have considerable LQ. The finding also indicates Shaku which is the only settlement in the region located on the Highlands records 0.03 basic economic LQ. This implies that all settlements in all type of terrain in the region are productive.

Findings of the study in Table 2 further revealed that two settlements with highest non-basic economic LQ are located within Plains (Egbako) and Niger Valley (Kuchita) with 0.07 LQ each. Followed by three settlements located in Niger Valley (Katcha and Gayankpa) and Uplands (Mukugi) with 0.04 non-basic LQ each. This indicates that Niger Valley is also among the terrains with high LQ in the region which implies that it is one of the most productive terrain in the region.

Analysis in Table 2 revealed that a significant number of settlements in the southern region of Niger State are located in the lower Niger Valley. This could be partly due to the fertile nature of the terrain and its potential in terms of both basic and non-basic economic activities. The region is also blessed with abundant water resources that flows throughout the year which has implication on agriculture and livelihood of the people of the region in general. The significant number of settlements located in the region, coupled with the fertile nature of the area and abundant water resources provide opportunities for which accounts for higher basic and non-basic economic activities and LQ of the region. The Niger Valley accounts for about 57% of the entire landscape, and is closely followed by the plains which occupies about 40% while the remaining 3% upland or highland of the terrain. The implication of these settlement classifications based on terrain and LQ is that the significant settlements located on the Niger Valley with their environs basic and non-basic economic activities highly vulnerable to flood hazards

on one hand and those on the low topography, rainfall regime and the drainage characteristics of the region.

Table 2. Settlement Classification Based on Terrain and Location Quotient

S/N	Settlements	Terrain	Basic Economic LQ	Non-Basic Economic LQ
1	Gbajibo	Niger Valley	0.03	0.02
2	Jangi	Niger Valley	0.03	0.03
3	Tyabo	Niger Valley	0.03	0.02
4	Takuma	Niger Valley	0.04	0.02
5	Kanzhi	Niger Valley	0.02	0.03
6	Muregi	Niger Valley	0.01	0.02
7	Enagi	Uplands	0.03	0.03
8	Guzan	Niger Valley	0.03	0.03
9	Lanle	Plains	0.03	0.03
10	Egbako	Plains	0.06	0.07
11	Ribiku	Uplands	0.03	0.02
12	Sacci	Niger Valley	0.02	0.02
13	Mambe	Niger Valley	0.02	0.03
14	Kuchita	Niger Valley	0.03	0.07
15	Edozhigi	Niger Valley	0.03	0.01
16	Batako	Niger Valley	0.04	0.03
17	Bisuigi	Niger Valley	0.02	0.03
18	Gada-Eregi	Plains	0.02	0.02
19	Baddegi	Niger Valley	0.03	0.02
20	Ndabisan	Plains	0.03	0.03
21	Katcha	Niger Valley	0.02	0.04
22	Tswachiko	Plains	0.03	0.01
23	Salawu	Plains	0.03	0.02
24	Kusoyaba	Plains	0.04	0.02
25	Tagagi	Plains	0.03	0.01
26	Baro	Niger Valley	0.02	0.02
27	Zago	Niger Valley	0.02	0.02
28	Shaku	Highlands	0.03	0.03
29	Mukugi	Uplands	0.04	0.04
30	Kalmo	Uplands	0.04	0.02
31	Sabon-Duma	Niger Valley	0.03	0.02
32	Kutiyaba	Plains	0.02	0.03
33	Ekun	Niger Valley	0.02	0.02
34	Edda	Niger Valley	0.02	0.02
35	Pele	Niger Valley	0.01	0.02
36	Muye	Niger Valley	0.01	0.03
37	Gayankpa	Niger Valley	0.02	0.04

Source: Field survey, 2020.

4. DISCUSSION

Findings of the study in terms of economic potentials of the region, reveals that communities are mainly engaged in basic economic activities; including the cultivation of food crops (rice, maize, beans, millet and yam); cultivation of cash crops (benisead, ground nut, vegetable, cassava and melon), plantation agriculture (palm, kola nut, cashew and sugar cane). Fishing (both individual and communal fishing) and livestock production (cow, poultry, sheep and goats). The study further revealed that there are four major non-basic economic activities which include trade, craft, hunting and canoe buildings which the communities are usually engaged in the region.

Findings in terms of basic economy revealed that Egbako has the highest LQ with an average score of 0.06, and is closely followed by Takuma, Batako, Kusoyaba, Mukugi and Kalmo, with an average LQ score of 0.04 each, while in terms of non-basic economy, the findings indicates that both Egbako and Kuchita have the highest non-basic LQ with an average score of 0.07, which were closely followed by Katcha, Mukugi and Gayankpa settlements with non-basic economic LQ and average scores of 0.04 each. This study explores the economic potentials of the Niger south region in Nigeria. The finding of this study is more comprehensive than a study conducted by Bukka et al. (2017). Bukka et al. (2017) revealed the economic potentials of Muwo district in Mokwa local government area, which is one of the total 39 districts in the region. This paper also explores application of LQ in regional economic potential assessments.

5. CONCLUSION

The study revealed the economic potentials of Niger south region in Nigeria and this depict the economic values of the flood region. The basic economic activities of the region revealed by the study includes the cultivation of food crops (rice, maize, beans, millet and yam); cultivation of cash crops (benisead, ground nut, vegetable, cassava and melon), plantation agriculture (palm, kola nut, cashew and sugar cane). Fishing (both individual and communal fishing) and livestock production (cow, poultry, sheep and goats), while, four major non-basic economic activities in the region include trade, craft, hunting and canoe buildings which the communities are usually engaged in the region. The study demonstrates that LQ is one of the best techniques in measuring economic potentials of regions. Therefore, the LQ is recommended for regional economic assessments.

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ACCESSIBILITY STUDY OF HISTORIC BUILDINGS AND CONTEMPORARY HERITAGE – ON THE EXAMPLE OF KIELCE'S PUBLIC UTILITY BUILDINGS

STUDIUM DOSTĘPNOŚCI OBIEKTÓW ZABYTKOWYCH ORAZ DZIEDZICTWA WSPÓŁCZESNOŚCI – NA PRZYKŁADZIE OBIEKTÓW UŻYTECZNOŚCI PUBLICZNEJ KIELC

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Abstract

Ensuring the accessibility of buildings and spaces is a common contemporary challenge, in particular for historic buildings and spaces as well as the heritage of contemporary culture. It involves all activities aimed at adapting facilities and space to the needs of people with various disabilities, including seniors. The problem of aging societies and increasing life expectancy forces extensive changes both in the approach to architectural and urban design as well as in the practice of making historic buildings accessible through architectural solutions. Particularly in existing public buildings, it becomes very important to pay attention to the specific needs and reduced psychophysical abilities of various groups of architecture recipients due to their age. For this reason, the article analyzes the accessibility of selected examples of historical objects (case studies) functioning in the structures of the modern city of Kielce – for several dozen years. In order to get acquainted with the functioning and architectural solutions of buildings, which are among the most frequented by the general public, in situ research was carried out, the multi-criteria method was used, enabling comparative analyzes and being an effective tool in making a precise assessment. The research was focused on the location of the city of Kielce, taking into account current reports and statistics indicating the largest increase in the number of people over 65 in the Świętokrzyskie Voivodeship. It was found that it is important to revise the approach and generally accepted functional and spatial solutions regarding the accessibility of this type of facilities.

Keywords: monuments, contemporary cultural assets, sharing, alternative access, people with disabilities

Streszczenie

Zapewnienie dostępności budynków i przestrzeni jest powszechnym współczesnym wyzwaniem w szczególności dla obiektów i przestrzeni zabytkowych oraz dziedzictwa kultury współczesnej. Wiąże się ono z wszelkimi działaniami służącymi dostosowaniu obiektów i przestrzeni do potrzeb osób z różnorodnymi niepełnosprawnościami, w tym seniorów. Problem starzejących się społeczeństw i wydłużania się długości życia wymusza szerokie zmiany zarówno w podejściu do projektowania architektoniczno-urbanistycznego, jak i praktyki w zakresie udostępniania zabytkowych obiektów poprzez rozwiązania architektoniczne. Szczególnie w istniejących budynkach użyteczności publicznej bardzo ważne staje się zwrócenie uwagi na specyfikę potrzeb i obniżone, z uwagi na wiek, możliwości psychofizyczne różnych grup odbiorców architektury.

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Z tego względu w artykule dokonano analizy dostępności wybranych przykładów historycznych obiektów (case studies), funkcjonujących w strukturach współczesnego miasta Kielce – od kilkudziesięciu już lat. W celu zapoznania się z funkcjonowaniem oraz rozwiązaniami architektonicznymi budynków, należących do najczęściej uczęszczanych przez ogół ludzi, przeprowadzono badania in situ, wykorzystano metodę wielokryterialną, umożliwiającą przeprowadzenie analiz porównawczych i stanowiącą skuteczne narzędzie w dokonaniu precyzyjnej oceny. Badania skoncentrowano lokalizacyjnie na obszarze Kielc, mając na uwadze aktualne raporty i statystyki wskazujące na największy przyrost liczby osób powyżej 65 lat w województwie świętokrzyskim. Stwierdzono, że istotna jest rewizja podejścia i ogólnie przyjętych rozwiązań funkcjonalno-przestrzennych w zakresie dostępności tego typu obiektów.

Słowa kluczowe: zabytki, dobra kultury współczesnej, udostępnianie, dostęp alternatywny, osoby z niepełnosprawnością

1. INTRODUCTION

The accessibility of buildings and space is a very current, widely promoted and increasingly loud issue in the media. Ensuring accessibility results from a statutory obligation [1-3], the constitution [4] and numerous other laws, resolutions [e.g. 5, 6] and is a contemporary challenge, in particular for historic buildings and spaces as well as the heritage of contemporary culture. It involves all activities aimed at adapting facilities and spaces to the needs of people with various disabilities, including seniors, and eliminating barriers in various spheres of social life. The problem of aging societies and increasing life expectancy forces extensive changes both in the approach to architectural and urban design as well as in the practice of making historic buildings accessible through architectural solutions. Particularly in public utility buildings, it becomes very important to pay attention to the specificity of needs and reduced, due to age, psychophysical capabilities of various groups of recipients of architecture. Therefore, it is important to revise the approach and generally accepted functional and spatial solutions regarding the accessibility of this type of facilities. Providing access to monuments and contemporary cultural goods also means adapting the facilities to the current utility, functional, technical and ecological standards. At the same time, in the implementation of these activities, the most important thing is the selection of appropriate, individual solutions that will not involve excessive burden or violation of valuable values, as it would be contrary to the principles of conservation protection [7, 8].

1.1. Purpose, scope and method of research

The main objective of the studies became to conduct accessibility analyses of selected public facilities that have been functioning in the structures of the modern city of Kielce for several dozen years.

These include both historic buildings and objects of high value spatial and architectural, structural and functional solutions as well as being a symbol and sign of history (PKS Kielce bus station).

In order to learn about the functioning and architectural solutions of buildings that are among the most frequented by the general public, such buildings were identified (case studies) and in situ studies were carried out. Attention was paid to ensuring the accessibility of the facility and its historic surroundings – as a comprehensive issue that should be analyzed in the context of the entire building, including: adaptation of access roads, parking spaces and contact space – entrances to the buildings. The issues of the solutions used to improve accessibility inside buildings have become equally important.

Taking into account the aging of the population and current reports and statistics indicating the largest increase in the number of people over 65 in the Świętokrzyskie Voivodship [9, 10], the city of Kielce was selected as the study site.

An important part of the work also became the identification of the most relevant criteria based on the actual needs and psychophysical condition of today's society.

The selection of public utility buildings included in the study was based on their importance and significance in the daily life of the residents of the city of Kielce and Kielce poviat, in terms of culture, access to public administration and public transport services.

The following public utility facilities in Kielce were analysed for accessibility

1. Kielce City Hall (1875).
2. Voivodeship House of Culture (1935).
3. Kielce Bus Station (1984, 2020).

1.2. Evaluation Criteria

Conducted previous research [9, 11-14] made it possible to formulate criteria as a tool for evaluating

the accessibility of the proposed significant facilities in the city of Kielce. The study used a multi-criteria method, which enabled comparative analyses and is an effective tool to help make an accurate assessment. Finally, 3 evaluation criteria were formulated:

CRITERION No. 1
External access to the facility:

- designation of a motor vehicle parking system near one of the main entrances, including the location of traveller drop-off points;
- unobstructed pedestrian routes leading to the entrance;
- entrances and exits at ground level;
- information at the entrance to the facility;
- wide door openings and easy door operation;
- sufficient space around the door to allow a person in a wheelchair to open and close the door.

CRITERION No. 2
Traffic in the internal space of the building – reaching all necessary functions and zones in the petitioner/customer service area:

- organization and hierarchy of space – a simple and logical functional layout of the interior space;
- available connections of the utility floors of the facility;
- easy access to elevators and toilets, including those adapted to the needs of people with disabilities, intuitive, obvious and accessible fire escape routes;
- spacious elevators equipped with access systems for people with limited perception, safe stairways that are convenient to use and will allow safe evacuation in emergency situations, non-slip surfaces for pedestrian routes;
- appropriate height, location and easy operation of buttons (for example in elevators);
- the visual aspect, the appropriate contrast of walls, floors, doors and signage.

CRITERION No. 3
Petitioner/customer service area:

- easy access to information points;
- appropriate height of service points;
- clear and universally understandable signage;
- the transmission of important information through two or more modalities – the senses of perception (touch, sound and visual content);
- hearing support systems.

2. MULTI-CRITERIA EVALUATION OF ACCESSIBILITY OF HISTORIC PUBLIC BUILDINGS

2.1. Kielce City Hall year of establishment: 1875. Designer: Architect Franciszek Kowalski

The building is located in the central part of the city, next to the Market Square, and is located at the junction with Piotrkowska street, Constitution Square and Leśna street.

CRITERION No. 1
External access to the facility:

- parking spaces for people with disabilities are located in the city's multi-level parking lot and are located in the closest proximity to the building – on the side of Constitution Square;
- the paths leading from the parking lot to the office have a smooth, paved and level surface, free of obstacles;
- entrances for people with disabilities are located on the side of Leśna street and from the side of Constitution Square. The entrance from the Market Square does not have a ramp, so it is not accessible to wheelchair users;
- on the side of Leśna street there is an entrance from the ground level, while from the side of Constitution Square the entrance to the interior is possible via a ramp;
- in the entrance area from Constitution Square, the space at the entrance door is of adequate size for wheelchair manoeuvring, the door is opened automatically, which is a great convenience for people with various types of limitations;
- the functional layout of the exterior is simple, logical and clear.

CRITERION No. 2
Traffic in the interior space of the building:

- there are elevators for vertical traffic in entrance areas dedicated to people with disabilities. An elevator from the side of Leśna street allows vertical traffic for the general public, while the elevator from the side of Constitution Square side requires assistants to be summoned, as the doors to it are closed on a daily basis. They are not, however, spacious elevators, especially from the side of Leśna street – it is not equipped with access systems for people with limited perception;
- the functional layout is simple and clear;
- fire escape routes are not cluttered with any obstacles;

- intermediate corridor areas for access to the various functions have a smooth non-slip surface;
- the surfaces of some of the walls, for example, in the entrance hall from Constitution Square, mimic stone and are uneven, which can be a hindrance for the visually impaired;
- the illumination of the entrance space from Constitution Square is not evenly distributed, which may pose difficulties for the visually impaired.

CRITERION No. 3
Petitioner service area:

- the main petitioner service area from the side of Market Square has been adapted for people with disabilities – it has a lowered console top, which is adapted for people with disabilities who use a wheelchair;
- an additional customer service area is located on the side of Constitution Square and has also been adapted for people with disabilities – by means of a lowered console top, which is adapted for people with disabilities who use a wheelchair;
- a person with a disability, moving from the entrance at Leśna street must walk a distance of about a few dozen meters to the main service area from the Market Square side;
- all informational signage is clear and legible;
- there are no assistive listening components such as induction loops in the Kielce City Hall facility.

Conclusions

The Kielce City Hall building has been adapted to the needs of people with disabilities to the maximum extent possible. Using the elevator from the side of Constitution Square requires calling an attendant, and from Leśna street – to travel dozen meters from the building entrance to the petitioner service area. The building's assets include legibility of the functional layout, spacious corridors, anti-slip surfaces. The difficulty may be to travel the distance from the entrance at Leśna street to the customer service centre.

Fig. 1. View from the Kielce Market Square

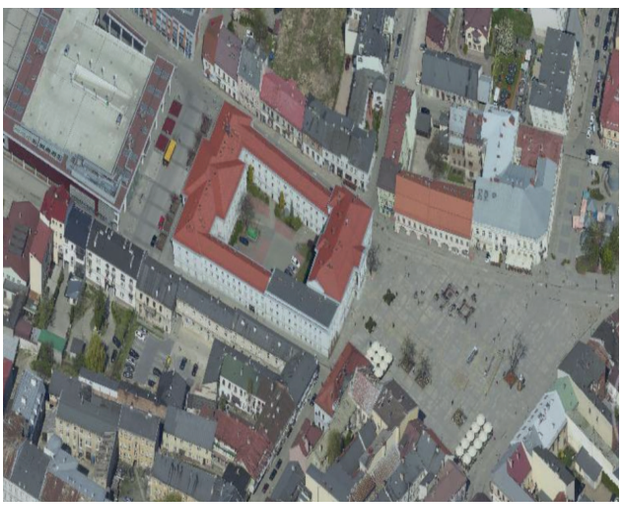

Fig. 2. Location of the City Hall building
Source: https://www.4dkielce.eu, accessed on: 02.2023.

Fig. 3. Customer service zone from the side of the Market Square

Fig. 4. Access zone for visitors from Constitution Square

Fig. 5. A Braille board from the side of Market Square

Fig. 6. A Braille board from the side of Market Square, board layout and details

Fig. 7. Entrance from the side of Constitution Square

Fig. 8. Horizontal communication – ground floor from the side Constitution Square

Fig. 9. Elevator from the side of Constitution Square, ground floor

Fig. 10. Elevator from the side of Constitution Square, first floor

Fig. 11. Horizontal communication on the first floor in the City Hall

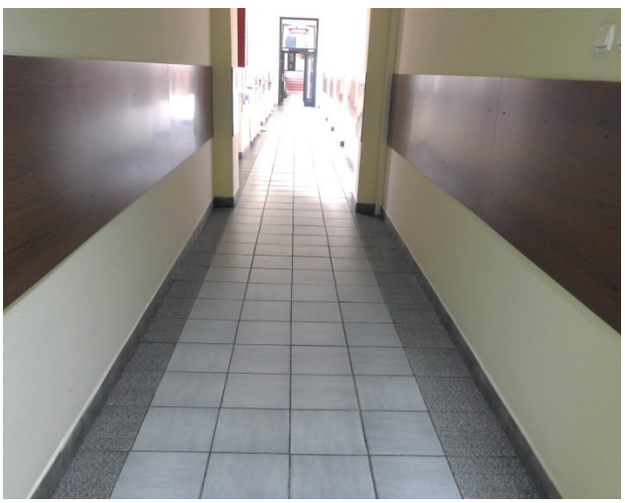

Fig. 12. Horizontal communication on the first floor in the City Hall

Photographs: the author, February 2023.

2.2. Voivodeship House of Culture (VHC), year of establishment: 1935. Designer: Architect Edgar Aleksander Norwerth

The VHC facility is located at the intersection of Ściegiennego and Al. Legionów streets. It is one of the structures under conservation protection, so there is no possibility of significant interventions in its functional layout.

CRITERION No. 1
External access to the facility:

- the main entrance to the building is inaccessible to people with disabilities who use wheelchairs, these people are to use the elevators located in the inner courtyard;
- parking spaces for the disabled are located closest to the vertical traffic zone;
- the road leading from the parking lot to the VHC building has a level and convenient surface for wheelchairs.

CRITERION No. 2
Traffic in the interior space of the building:

- the main customer service area in the building's main hall is fully adapted for people with disabilities;
- the functional layout and access to toilets for the disabled are simple and clear;
- fire escape routes are not cluttered with any obstacles;

- the corridor areas are wide and spacious, with smooth anti-slip surfaces;
- connections of the utility floors of the facility are possible by means of external elevators.

CRITERION No. 3
Customer service area:

- easy access to information points;
- appropriate height of customer service points;
- no hearing support elements.

Conclusions

The VHC building has been adapted to people with disabilities to the maximum extent possible. For conservation reasons, the facility does not have elevators installed inside the building as of today. They were introduced at the rear of the building in the courtyard area. The building's strengths include spacious corridors and staircases, as well as a service and cloakroom area that is adapted for people with disabilities who use wheelchairs. The introduction of external elevators at the facility has made it a popular destination and is used especially by wheelchair users.

Fig. 13. View from the front side

Fig. 14. View of the WDK building
Source: https://www.4dkielce.eu, accessed on: 02.2023

Fig. 15. Parking spaces for the disabled by the building

Fig. 16. Horizontal communication in the hall main building

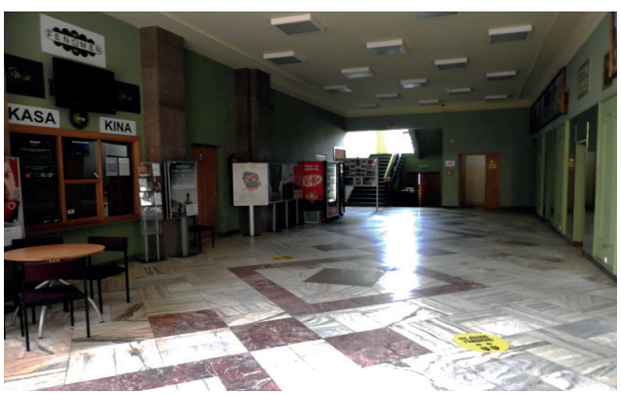

Fig. 17. Horizontal communication in the hall main building

Fig. 18. Vertical communication in the main hall of the building

Fig. 19. Elevator for the disabled at the back of the building
Photographs: the author, February 2023.

Fig. 20. Disabled platform at the back of the building

2.3. Kielce Bus Station, year of establishment: 1984, year of reconstruction: 2020.
Designer: Architect Edward Modrzejewski.
Author of the reconstruction: Marcin Kaminski Bartosz Bojarowicz Architekci s.c. Kielce

CRITERION No. 1
External access to the facility:

- parking spaces for people with disabilities are located in close proximity to the building;
- the pedestrian routes leading to the entrance are free of obstacles, and the pavements have been shaped with warning, guidance and attention fields – in accordance with the requirements of the Pavement Marking System, which is used to identify sites and corridors. The combination of textures allows people with visual impairments to move freely;
- all entrances to the building are adapted for the disabled and are located at ground level;
- surfaces leading from the parking lot and traffic system to the Bus Station building have a smooth even surface;
- signage and information at the entrances to the building are clear and legible;
- the main entrance areas of the building use sliding doors with appropriate widths, which significantly facilitates use;
- the space at the door is of adequate size and allows free manoeuvring for wheelchair users;
- the functional layout of the exterior is simple, logical and clear.

CRITERION No. 2
Traffic in the building:

- the functional layout of the building is simple and clear, corridors and horizontal traffic spaces are wide and do not contain elements that make traffic difficult for people with disabilities, and have smooth non-slip surfaces;
- the first floor level is accessible to all users by means of spacious elevators adapted for the disabled;
- the signage of the vertical and horizontal traffic zone, as well as the descriptions of the doors of toilets for people with disabilities, the main service areas – are fully legible and intuitive;
- traffic areas in the building have contrast elements for the visually impaired. Contrasts have been used on both walls and floors, which can be a significant convenience for the visually impaired;
- fire escape routes are not cluttered with any obstacles;
- toilet and elevator door signs include buttons at the appropriate height with Braille markings.

CRITERION No. 3
Customer service area:

- convenient passenger information system: graphic, audio and tactile messages;
- information desks are located in the main hall of the building;
- access to the information points in the building is simple and clear;
- the information area and ticket office area have been adapted for people with disabilities, the lowering of the countertop to serve wheelchair users is valuable;
- the information and cash desk area is equipped with induction loops and a sign language interpreter service;
- for the blind and visually impaired, room markings in Braille have also been introduced;

- on each floor there are toilets adapted to the needs of people with reduced mobility;
- on the ground floor and first floor of the building, in the general traffic areas of the hall, there are Braille boards containing a plan of the station and the areas around it, which facilitates orientation in the space for the blind and visually impaired.

Conclusions

The Bus Station building is an example of a fully accessible facility.

The original facility, used since July 1984, was thoroughly modernized and rebuilt in 2022, in accordance with the principles of universal design, while maintaining its original and unique character. In the new Communication Center, all barriers have been eliminated and spaces friendly to people with disabilities have been created.

The building's big assets are the pavement texturing system used in the facility, Braille signs, contrasting elements on the floor and walls, a simple clear layout of internal traffic, fully accessible service areas, toilets and elevators adapted to people with disabilities.

In the external space, parking spaces for people with disabilities have been designed, levels around the building have been leveled, ramps and accessible elevators have been prepared. The facility received a distinction in the 7th edition of the "Accessibility Leader" Architectural and Urban Competition (October 2022), the aim of which is to promote universal design and the best urban and architectural solutions in the field of adapting buildings and spaces to the needs of people with disabilities.

Fig. 21. Entrance to the bus station building

Fig. 22. Location of Bus Station Building. Source: https://www.4dkielce.eu, accessed on: 02.2023.

Fig. 23. Horizontal communication zone towards the hall and guidance paths

Fig. 24. Horizontal communication in the main hall of the building

Fig. 25. Horizontal communication zone for platforms and paths leading to them

Fig. 26. Horizontal communication zone on the platforms

Fig. 27. Vertical communication zone – escalators and guide paths in the main hall

Fig. 28. Vertical communication zone – fixed stairs and guidance paths

Fig. 29. Typhlographic board on the ground floor hall

Fig. 30. Typhlographic board on the first floor hall

Fig. 31. Lowered console table in the service area Photographs: the author, February 2023

Fig. 32. Vertical communication in the hall-elevator

3. DISCUSSION

Based on the conducted visions of local objects and interviews with the manager and staff, it should be emphasized that two factors become the most important in the implementation of making objects available: 1) the choice of an appropriate solution ensuring the greatest possible protection of the value of the monument, 2) financial resources. In general, it can be stated that the presented buildings (City Hall of Kielce, Voivodeship Cultural Center) in most cases have architecture and internal space adapted to people with disabilities, but not to the full extent.

This is due in large part to the period in which these buildings were designed and built. In the situation of some structures, it is often difficult or even impossible to meet all the requirements for full accessibility, due to the specificity of the structure (the building of the Kielce City Hall), or conservation considerations (monument: Voivodeship House of Culture in Kielce). Then the situation forces the use of alternative solutions (e.g., Kielce Cultural Centre). In addition, the solutions that are introduced into the facilities at later stages of use are not exactly comfort solutions and those that should be considered equivalent to those envisioned at the stage of design or radical reconstruction of the facility.

To sum up, making Kielce facilities available is usually associated with the elimination of architectural barriers. However, this does not only boil down to the introduction of new architectural solutions, but also to undertaking activities in the sphere of communication and information. They are undoubtedly a safe solution for the protection of historic values. In the implementation of providing access to historic buildings and objects of contemporary culture, priority has become available zones of entrances to buildings and enabling the overcoming of vertical communication barriers through the use of appropriate cranes and the ability to move around the facility (free, collision-free access to the service, reception, information zone). In the external space, the limiting factor is usually the technical condition of the surface with cavities, depressions and made of inappropriate materials (e.g. surfaces made of granite paving stones, the so-called cat heads). This significantly hinders the movement of people in wheelchairs, the elderly, the blind and the visually impaired. The vast majority of the improvements introduced so far refer to conventional and formal solutions. These are more conservative concepts, with characteristic devices dedicated specifically to the elderly and people with physical disabilities. A unique solution is the bus station, radically reconstructed in the 21st century. It should be articulated that the entire architectural and urban layout constitutes a fully accessible space – based on the assumed evaluation criterion.

4. SUMMARY AND CONCLUSIONS

The conducted analyzes of Kielce objects proved that ensuring the accessibility of monuments is still a complex and extensive issue. Adapting a historic building to the needs of people with various disabilities is very difficult, and even impossible to the full extent. To a large extent, full access is associated only with broadly understood modernization, i.e. construction works related to the reconstruction, extension or superstructure of the building, with interference in historic values.

No criterion	Description of the criterion	Kielce City Hall	Voivodeship House of Culture	Kielce Bus Station
CRITERION No. 1 External access to the facility	designation of a motor vehicle parking system near one of the main entrances, including the location of traveller drop-off points	+	+	+
	unobstructed pedestrian routes leading to the entrance	+	+	+
	entrances and exits at ground level	+	+	+
	information at the entrance to the facility	+	+	+
	wide door openings and easy door operation	+	+	+
	sufficient space around the door to allow a person in a wheelchair to open and close the door	+	+	+
CRITERION No. 2 Traffic in the internal space of the building – reaching all necessary functions and zones in the petitioner/ customer service area	organization and hierarchy of space – a simple and logical functional layout of the interior space	+	–	+
	available connections of the utility floors of the facility	+	–	+
	easy access to elevators and toilets, including those adapted to the needs of people with disabilities, intuitive, obvious and accessible fire escape routes	+	+	+
	spacious elevators equipped with access systems for people with limited perception, safe stairways that are convenient to use and will allow safe evacuation in emergency situations, non-slip surfaces for pedestrian routes	+	–	+
	appropriate height, location and easy operation of buttons (for example in elevators)	+	+	+
	the visual aspect, the appropriate contrast of walls, floors, doors and signage	–	+	+
CRITERION No. 3 Petitioner/customer service area	easy access to information points	+	+	+
	appropriate height of service points	+	+	+
	clear and universally understandable signage	+	+	+
	the transmission of important information through two or more modalities – the senses of perception (touch, sound and visual content	+	+	+
	hearing support systems	–	+	+
	SUMMARY	**15(+)/2(–)**	**14(+)/3(–)**	**17(+)**

The studies made it possible to formulate the most important conclusions and recommendations helpful in designing and managing the space of historic buildings and contemporary heritage:

- The key aspect is to recognize the opinions of all participants in the access process (manager, monument conservator, designers, staff and users, including those with disabilities) and often to seek an appropriate compromise to preserve the protection of the monument and introduce solutions to ensure accessibility.
- Introducing modern solutions consistent with the image of the facility, not related to the risk of damage to the historic matter, along with the development of a concept of providing access that will satisfy all users and visitors, including:
  - designation of alternative routes that are easy to walk, the use of adjustable ramps;

  - ensuring safe entrances and exits from the building and appropriate width of communication routes;
  - proper execution, use and proper maintenance of floors, sidewalk surfaces, use of handles, handrails, limiters, bumpers, guiding systems – individually tailored to a given facility and situation.
- Offering a means of transport, help and assistance from the staff – which will affect and encourage a longer stay, providing properly prepared specialists, interpreters, sign language interpreters.
- Special attention to innovation and consideration of the needs of future seniors, taking into account the dynamic changes in relationships between people and the virtual environment, providing a website that takes into account the rules of accessibility also in terms of ICT, comprehensive information about the accessibility of the facility and the possibility of reaching the facility and the communication and information zone.
- Systematic and uninterrupted work on making facilities and the most complete offer available to all people, including selection of appropriate sharing options that do not excessively affect the value of the monument, support for various groups of recipients through specialized audio guides, guides, messages in Braille, introduction of Q-codes.

In conclusion, it is worth re-articulating that every space, including the cultural environment, should enable all people to use it as independently and consciously as possible. This applies to both historic buildings and areas, including buildings and areas with cultural potential.

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DYNAMIC ANALYSIS OF A STEEL-CONCRETE RAILWAY BRIDGES OF LANGER TYPE UNDER THE INFLUENCE OF A MOVING LOAD

ANALIZA DYNAMICZNA STALOWO-BETONOWEGO MOSTU KOLEJOWEGO TYPU LANGERA POD WPŁYWEM OBCIĄŻENIA RUCHOMEGO

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Abstract

The studying the dynamic response of steel-concrete railway bridges of Langer type is huge importance of ensuring the safety of such structures under high-speed train loads. Numerical simulations at the design stage require knowledge of the modal characteristics: natural frequencies, shapes and damping. In addition, in the dynamics of railway bridges subjected to high-speed trains, it is important to check the impact of dynamic effects on the ultimate and serviceability limit states. As part of the investigations displacements and accelerations of selected measurement points arising from driving the test rolling stock are analyzed. In the first stage, calculations of the eigenvalues and the corresponding eigenvectors were carried out in the Robot program for two variants of mass description (distributed and discrete). In the second stage, dynamic train passages for various vehicle speeds were examined in terms of displacements and accelerations of measurement points by using the authors' program MES3D.

Keywords: modal analysis, Newmark method, FEM model, moving load, steel-concrete railway bridges of Langer type

Streszczenie

Badanie odpowiedzi dynamicznej stalowo-betonowych mostów kolejowych typu Langera ma ogromne znaczenie dla zapewnienia bezpieczeństwa takich obiektów pod obciążeniem pociągów dużych prędkości. Symulacje numeryczne na etapie projektowania wymagają znajomości charakterystyk modalnych: częstotliwości drgań własnych, form i tłumienia. Dodatkowo w dynamice mostów kolejowych poddanych działaniu pociągów szybkobieżnych istotne jest sprawdzenie wpływu efektów dynamicznych na stany graniczne nośności i użytkowalności. W ramach badań analizowano przemieszczenia i przyspieszenia wybranych punktów pomiarowych powstałych od jazdy taborem próbnym. W pierwszym etapie przeprowadzono obliczenia wartości własnych i odpowiadających im wektorów własnych w programie Robot dla dwóch wariantów opisu masy (rozłożonej i dyskretnej). W drugim etapie zbadano przebiegi dynamiczne dla różnych prędkości pociągów pod kątem przemieszczeń i przyspieszeń punktów pomiarowych za pomocą autorskiego programu MES3D.

Słowa kluczowe: analiza modalna, metoda Newmarka, model MES, obciążenie ruchome, stalowo-betonowe mosty kolejowe typu Langera

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1. INTRODUCTION

Nowadays, transport needs are still increasing. Bridges ensure a collision-free intersection of pedestrian routes with roads, railways and waterways. These structures are often characterized by interesting architectural forms. This is mainly due to the use of modern high-strength materials and the increase in the possibilities and accuracy of design calculations, e.g. using the finite element method (FEM) in the design process. Numerical calculations are often verified by in-situ experimental studies [1-8]. The numerical simulations of dynamic behavior at the design stage require knowledge of the modal characteristics of the structural system. These are sets of natural frequencies, mode shapes, and damping. There are two general methods for determining the modal characteristics of structures: analytical and experimental. The first one usually employs a modal analysis performed on a numerical model [9-15], which can be done at the design stage but has limitations resulting from simplifying assumptions, mainly concerning damping, joint stiffness, and boundary conditions. On the other hand, the experimental method comprises conducting a field test to determine the modal characteristics of the real structure. For identification, controlled experiments are performed [16] and most often analyzed by experimental modal analysis (EMA) [17, 18] or operational modal analysis (OMA) [18, 19].

In addition, in the dynamics of railway bridges subjected to high-speed trains, it is important to check the impact of dynamic effects on the ultimate and serviceability limit states. Serviceability limit states are related to driving safety and passenger comfort. An increase in the operating speed results in increased actions by railway vehicles on the structure and entails the need to solve numerous complex engineering problems. From the perspective of traffic safety and travel comfort (particularly relevant in case of high operating speeds) it is important to determine vibration amplitudes for both the vehicle and bridge spans and the interacting forces between them. Numerical simulations of bridge load tests are often performed before they are put into service. Their purpose is to verify the actual condition of the structure and correlation of measurement results with theory. This enables, among others, commissioning objects without the need to carry out costly measurements of vehicles acting on the structure other than those for which designated tests are required. Currently structural analyses are performed mainly using finite element computer programs. They provide a very accurate representation of a structure with beam, shell and solid elements. The modelling method is chosen depending on the objective of the analysis. Technical problems related to the description of the dynamic response of railway bridges are discussed in [20-27].

From the point of view of bridge structures, the moving load is one of the most important components of the load. The analysis of the impact of the moving load on bridge structures is carried out numerically or experimentally. The numerical approach requires attention to the following issues: creating computational models of the vehicle and bridge, creating computational programs to solve equations of motion. To solve this problem, it is beneficial to work with discrete computational models using the finite element method. The experimental approach focuses on verifying the adopted numerical models and monitoring the condition of bridge structures. One of the key elements of structural health monitoring (SHM) is operational modal analysis. Identification of the modal properties of a structural system is a process of correlating the dynamic characteristics of a numerical model with the physical properties of the system obtained from experimental measurements. This allows engineers to analyze structural behavior and identify potential structural failures.

Polish State Railways's (PKP) development plans include the introduction of express passenger trains moving at speeds of up to 250 km/h on the Central Railway Main Line (CMK). One of the scientific and technical problems related to this is to check the dynamic strain of bridge structures on CMK in new operating conditions. The basic group of these objects are composite beam bridges with a load-bearing structure consisting of steel plate girder main beams and a reinforced concrete bridge slab. The presented work concerns the numerical analysis of the bridge structure along the PKP line No. 4 CMK on the section Szeligi - Idzikowice at km 26.571/26.578 under dynamic load. The subject of the research is the supporting structure of the viaduct. It is a steel Langer arch (rigid deck and slender arch) located over the S8 expressway (Figs. 1, 2). In the first stage, calculations of the eigenvalues and the corresponding eigenvectors were carried out. The modal analysis of the bridge was performed for a spatial FEM model. The calculations were carried out in the Robot program for two variants of mass description (distributed and discrete). In the second stage, dynamic passages for various train speeds were examined in terms of displacements and accelerations of measurement points. Two variants of the load were

adopted in the work. The first consists of ES64U4 electric locomotive located at the beginning and end of the train and four 154A type passenger cars (Fig. 3a). In the first variant the load moves at the following speeds: 10, 40, 80, 120, 160, 180 and 200 km/h. Due to the symmetry of the structure and the measuring points, the load motion was simulated in one direction. The second variant consists of the ETR610 Pendolino located at the beginning and end of the train and five passenger cars (Fig. 3b). The following velocities were assumed: 10, 200, 230 and 250 km/h. Seven recording points were defined on the structural model. In three locations on one side vertical displacements, horizontal displacements in two perpendicular directions and vertical accelerations were recorded, while in all other points only vertical displacements were tracked. The calculations were carried out using the proprietary MES3D program developed by the authors.

In summary, the manuscript focuses on two themes. At first, the analytical identification of the bridge modal response is sought (eigenfrequencies are determined in two variants of mass representation: concentrated and distributed) to enable and improve further numerical computations. Secondly, the structural response is predicted, in terms of displacements and accelerations, for various vehicle speeds of two train load sets. Finally, conclusions are formulated on the basis of the obtained data to address the serviceability of the object and human voyage comfort. The studying the dynamic response of steel-concrete railway bridges of Langer type is huge importance of ensuring the structural integrity and safety of such bridges under high-speed train loads.

Fig. 1. Side view of the bridge (https://www.google.com/maps)

Fig. 2. Bottom view of the bridge (https://www.google.com/maps)

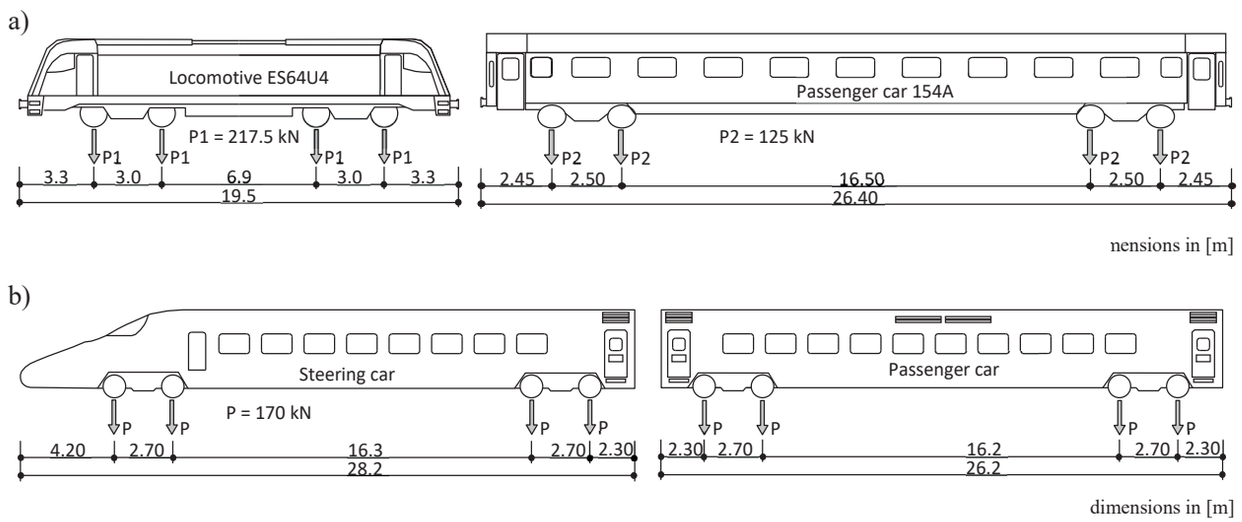


Fig. 3. Two variants of moving load: a) ES64U4 electric locomotive located at the beginning and end of the train and four 154A type passenger cars, b) ETR610 Pendolino located at the beginning and end of the train and five passenger cars

2. MATERIAL AND METHODS

2.1. Modal analysis

One of the basic issues in dynamics of structures is to determine the conditions under which the system can move around the equilibrium position without the action of external forcing forces. The matrix differential equation of motion describing this process without damping can be written as:

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{0} \tag{1}$$

where:
M – mass matrix,
K – stiffness matrix,
q – vector of nodal displacements,
ω – eigenfrequency.

Predicting a harmonic solution, suppose:

$$\ddot{\mathbf{q}} = -\omega^2\mathbf{q} \tag{2}$$

Substituting expression (2) into equation (1) we obtain a homogeneous matrix equation that must be satisfied at any arbitrary time t.

$$\left(\mathbf{K} - \omega^2\mathbf{M}\right) = \mathbf{0} \tag{3}$$

The trivial solution does not yield the searched conditions of the problem as it corresponds to equilibrium at rest. The condition for the existence of non-zero solutions is the equation:

$$\det\left|\mathbf{K} - \omega^2\mathbf{M}\right| = 0 \tag{4}$$

After solving the determinant, we obtain an algebraic equation with respect to ω whose roots are the eigenfrequencies of the structure. These roots are real positive numbers, and their number is equal to the number of dynamic degrees of freedom (multiple roots may be present). Each eigenvalue ω_i corresponds to a solution $\mathbf{q} = \mathbf{w}_i$ such that:

$$\left(\mathbf{K} - \omega_i^2\mathbf{M}\right)\mathbf{w_i} = \mathbf{0} \tag{5}$$

The vector $\mathbf{w}_i$ is called the eigenvector of the i-th mode of vibration. It determines the distribution of displacements during vibrations with the frequency ω_i. Eigenvectors are defined up to a constant factor, so they can be normalized arbitrarily. The set of eigenvectors forms an eigenmatrix **W**.

$$\mathbf{W} = \left[\mathbf{w_1}, \mathbf{w_2}, \ldots, \mathbf{w_d}\right] \tag{6}$$

where d is the number of dynamic degrees of freedom.

Modal analysis allows us to effectively solve structural problems related to vibration at the design or operation stage. Its main application is to compare the frequency of excitation of the system with its natural frequencies. If these values are close to each other or overlap, the phenomenon of resonance arises. During resonance, vibration amplitudes can be multiplied multiple times, which may lead to failure or complete destruction of the structure.

2.2. Newmark method (average acceleration)

Newmark implicit time integration method is one of the oldest and most powerful methods used for dynamic analysis of structures and wave propagation problems. Newmark's method, [28], allows the direct solution of a second-order differential equation or a system of second-order differential equations. Consider the matrix equation of motion:

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}\dot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{P} \tag{7}$$

with initial conditions:

$$\mathbf{q}(0) = \mathbf{q}_0 \tag{8}$$

$$\dot{\mathbf{q}}(0) = \dot{\mathbf{q}}_0 \tag{9}$$

where:
M – mass matrix,
K – stiffness matrix,
C – damping matrix,
q – vector of nodal displacements,
P – vector of nodal load.

Vector **P** for $t \geq 0$ contains components that are arbitrary, continuous functions of time. The equation in the general case is a description of some non-stationary dynamic process. Analytical solution of the equation of motion for arbitrary forces may prove difficult, hence direct methods of numerical integration are of great practical importance. If we choose a discrete set of points t_i on the time axis with the integration step $h = t_{i+1} - t_i$, then the representation of the solution of the equation will be the set of vectors displacements and velocities. The calculations use the Newmark method, which can be formulated by expanding the function into a Taylor series

$$\dot{\mathbf{q}}_{i+1} = \dot{\mathbf{q}}_i + h\ddot{\mathbf{q}}_i + \frac{1}{2}h^2\dddot{\mathbf{q}}_i + \cdots \tag{10}$$

$$\mathbf{q}_{i+1} = \mathbf{q}_i + h\dot{\mathbf{q}}_i + \frac{1}{2}h^2\ddot{\mathbf{q}}_i + \frac{1}{6}h^3\dddot{\mathbf{q}}_i + \cdots \tag{11}$$

Higher derivatives are eliminated from the formulas (12) and (13), leaving terms of the second order at most. We replace the remaining terms of the Taylor expansion with arithmetic means for velocities and weighted averages for displacements.

$$\dot{\mathbf{q}}_{i+1} = \dot{\mathbf{q}}_i + \frac{1}{2}h\ddot{\mathbf{q}}_i + \frac{1}{2}h\ddot{\mathbf{q}}_{i+1} \tag{12}$$

$$\mathbf{q}_{i+1} = \mathbf{q}_i + h\dot{\mathbf{q}}_i + \left(\frac{1}{2} - \beta\right)h^2\ddot{\mathbf{q}}_i + \beta h^2\ddot{\mathbf{q}}_{i+1} \tag{13}$$

where: parameter $\beta \in <0; \frac{1}{2}>$.

From the last relationship, we get:

$$\ddot{\mathbf{q}}_{i+1} = \frac{1}{\beta h^2}\left[\mathbf{q}_{i+1} - \mathbf{q}_i - h\dot{\mathbf{q}}_i - \left(\frac{1}{2} - \beta\right)h^2\ddot{\mathbf{q}}_i\right] \tag{14}$$

In the Newmark method as an interpolation method, the collocation condition is satisfied at the time 'i+1'.

$$\mathbf{M}\ddot{\mathbf{q}}_{i+1} + \mathbf{C}\dot{\mathbf{q}}_{i+1} + \mathbf{K}\mathbf{q}_{i+1} = \mathbf{P}_{i+1} \tag{15a}$$

$$\begin{aligned}&\frac{1}{\beta h^2}\mathbf{M}\left[\mathbf{q}_{i+1} - \mathbf{q}_i - h\dot{\mathbf{q}}_i - \left(\frac{1}{2} - \beta\right)h^2\ddot{\mathbf{q}}_i\right] + \\ &+ \mathbf{C}\left[\dot{\mathbf{q}}_i + \frac{1}{2}h\ddot{\mathbf{q}}_i + \frac{1}{2}h\frac{1}{\beta h^2}\left[\mathbf{q}_{i+1} - \mathbf{q}_i - h\dot{\mathbf{q}}_i - \right.\right. \\ &\left.\left. - \left(\frac{1}{2} - \beta\right)h^2\ddot{\mathbf{q}}_i\right]\right] + \mathbf{K}\mathbf{q}_{i+1} = \mathbf{P}_{i+1}\end{aligned} \tag{15b}$$

After tidying up, we can write:

$$\mathbf{A} \cdot \mathbf{q}_{i+1} = \mathbf{R}_{i+1} \tag{16}$$

where:

$$\mathbf{A} = \frac{1}{\beta h^2}\mathbf{M} + \frac{1}{2\beta h}\mathbf{C} + \mathbf{K}$$

$$\begin{aligned}\mathbf{R}_{i+1} = \mathbf{P}_{i+1} + &\left[\frac{1}{\beta h^2}\mathbf{q}_i + \frac{1}{\beta h}\dot{\mathbf{q}}_i + \left(\frac{1}{2\beta} - 1\right)\ddot{\mathbf{q}}_i\right]\mathbf{M} + \\ + &\left[\frac{1}{2\beta h}\mathbf{q}_i - \left(\frac{1}{2\beta} - 1\right)\dot{\mathbf{q}}_i + \frac{h}{2}\left(\frac{1}{2\beta} - 2\right)\ddot{\mathbf{q}}_i\right]\mathbf{C}\end{aligned}$$

When initiating the solution process, the vector $\ddot{\mathbf{q}}_0$ is needed to determine the modified vector $\mathbf{R}_1$. It can be calculated by writing the collocation equation for time t = 0 as

$$\ddot{\mathbf{q}}_0 = \mathbf{M}^{-1}\left(\mathbf{P}_0 - \mathbf{C}\dot{\mathbf{q}}_0 - \mathbf{K}\mathbf{q}_0\right) \tag{17}$$

The numerical solution is always burdened with an error resulting from the use of a finite step size, the so-called discretization error. In addition, there may be effects of the so-called parasitic damping, which result from the very formulation of the method. In the case of the Newmark method, the stability of the scheme is determined by the value of the β parameter. For $0.25 \leq \beta \leq 0.5$ the scheme is unconditionally stable. For the range $0 \leq \beta < 0.25$ the scheme is conditionally stable with a stability limit.

$$h < \frac{2}{\omega\sqrt{(1-4\beta)}} \tag{18}$$

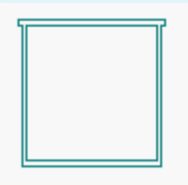
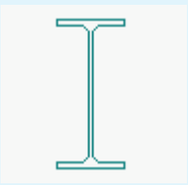
In our calculations, an unconditionally stable variant with a beta parameter of 0.25 was used. For the practical application of stability conditions, it is necessary to know the highest natural frequency of the analyzed structure. This requirement greatly limits the possibilities for calculating the limiting time step. In addition to stability, the accuracy of the solution should also be considered. Unfortunately, the higher the stability, the lower the accuracy.

3. EXAMPLE – DESCRIPTION, CALCULATIONS, RESULTS AND DISCUSSION

3.1. Description of steel-concrete railway bridge of Langer type

The supporting structure of the viaduct is a steel Langer arch with rigid deck and slender arch (Fig. 4). Technical parameters of the viaduct: theoretical length 75 m, construction height 1.59 m, crossbar spacing 2.5 m, main girder spacing 5 m, hangers spacing 7.5 m. The platform was built of a steel plate girder and an orthotropic slab. Steel fixed and movable double-roller bearings provide support for the spans. For each track there are separate supports of the viaduct, which are offset from each other because the road under the viaduct is laid diagonally. Franc piles support the massive abutments of the second geotechnical category and retaining walls. The structure is equipped with a railway superstructure made of UIC60 rails with SB type fastening on reinforced concrete sleepers, where rail profiles are placed. The cross-section of the arch is a steel box with a height of 1534 mm and a width of 730 mm. These dimensions are constant along its entire length, but the thickness of the sheet varies: at the beginning and end of the arch it is 28 mm, while in the middle it is 24 mm (Table 1). The bottom chord is built in a similar way, it is also a steel box with a constant cross-section along the entire length: 1792 mm high and 730 mm wide and of different sheet thickness: 28 mm at the two ends of the structure and 20 mm in

Table 1. Sections of the supporting structure of the viaduct

Section				
Description	Upper chord – external elements	Upper chord – middle elements	Bottom chord – external element	Bottom chord – middle elements
A [cm^2]	1494.24	1377.28	1660.15	1385.12
Ix [cm^4]	2839631.79	2555241.10	3769659.90	2952872.06
Iy [cm^4]	4374418.85	4165103.38	6643890.18	5966576.30
Iz [cm^4]	1235736.37	1115075.81	15317361.91	1218094.99
Section				
Description	Crossbeam – upper chord	Crossbeam of the deck slab	Hanger	Sling
A [cm^2]	560.40	306.00	50.27	350.00
Ix [cm^4]	470254.32	833.00	398.78	5269.89
Iy [cm^4]	423258.02	256900.00	201.06	1429.17
Iz [cm^4]	278602.03	14440.00	201.06	72916.67

the middle. The load-bearing structure of the deck slab is made of the HEB profile. These elements have been moved to their actual position using offsets. The arched upper chord is connected with rectangular box section cross-beams. The structure was modeled in the Autodesk Robot program as a spatial structure. Bar elements were used to model the steel parts. The reinforced concrete slab with a thickness of 30 cm, on which the track is located, was modeled using shell elements without reinforcement. The computational model contained 548 nodes, 168 bar elements and 120 shell elements. The total number of generalized coordinates is 3288. The dynamic analysis took into account the mass of equipment elements located on the bridge: brackets, balustrades, track elements. The value per one girder was equal to 1950 kg/m, added to the longitudinal members of the bottom chord.

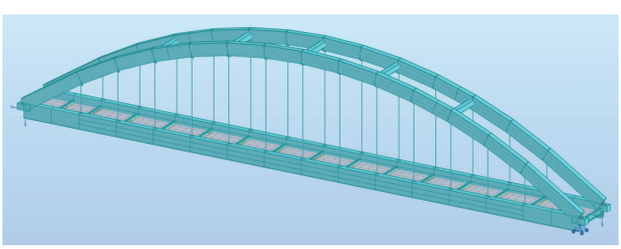


Fig. 4. FEM model of the steel-concrete railway bridge of the Langer type

3.2. Modal analysis of railway bridge of Langer type

The modal analysis was performed in the Robot program with continuous and discrete mass field distributions. In engineering practice, we are most often interested in the lowest vibration frequencies. In the variant with continuous mass distribution we also obtain vibration modes related to the movement of individual structural elements, e.g. hangers (Fig. 5), which might not be of interest to us. Hangers, which are fragment of structure in case continuous mass distribution can give independent forms of vibration. However, their influence on the vibration of the entire structure is small. Such vibration modes usually do not occur with discrete mass distribution. Independent forms of hanger vibrations are directly related to the way they are installed in the structure. The hangers are hinged to the gusset plate. Slight differences between the vibration frequencies result from the ways of describing the mass distribution for both models in FEM (Table 2). The comparison of the first six vibration frequencies for the model with concentrated masses and with the distributed mass model is shown in Table 2. Further calculations and illustrations of the vibration mode shapes are given for the to the discrete mass model (Fig. 6).

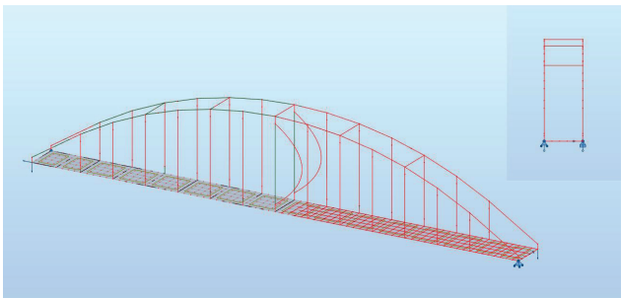
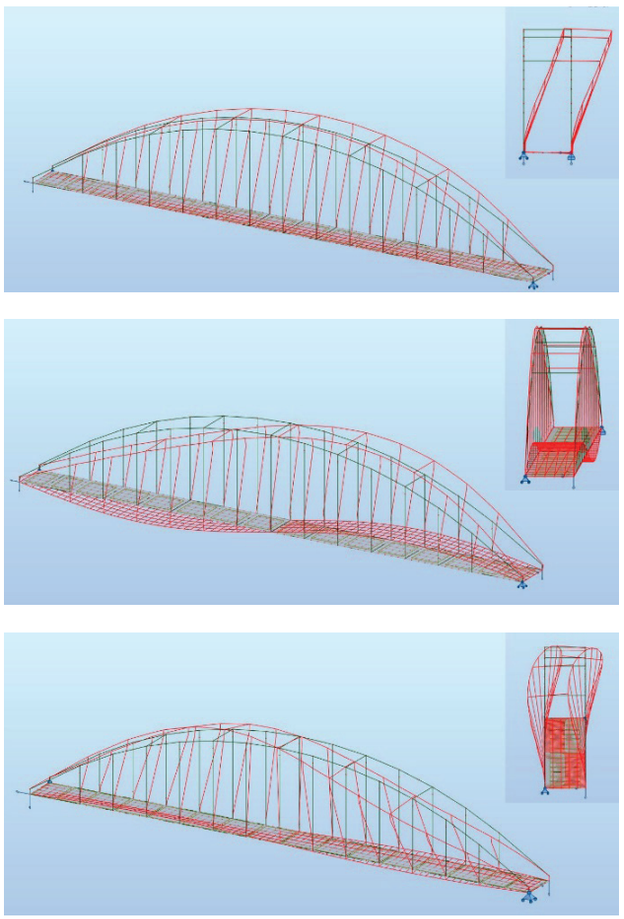


Fig. 5. Vibration mode shape related to the local movement of an individual hanger

Table 2. The comparison of the first six vibration frequencies for the model with concentrated masses and with the distributed mass model

Nr form	Frequency [Hz]	
	Discrete mass	Distributed mass
1	1.09	1.10
2	2.14	2.15
3	2.44	2.48
4	3.19	3.21
5	3.69	3.68
6	4.77	4.84



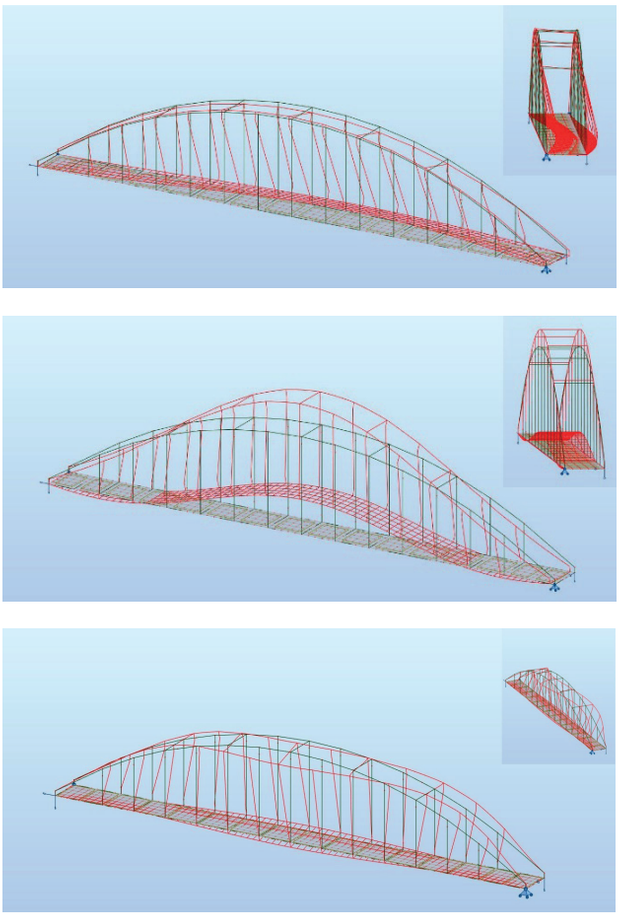


Fig. 6. First six mode shapes of numerical model with discrete mass distribution

3.3. Calculations of railway bridge under the influence of the moving load

The calculations under the influence of the moving load were made in the MES3D program using the unconditionally stable variant of the Newmark method [28]. Experience shows that in the case of engineering analyzes of real objects, it is sufficient to assume that the load operates in a non-inertial manner, the time of computer simulations is significantly shorter in such case.

The calculations did not directly take into account the elastic characteristics of the subgrade (track, ballast), the fact of indirect load transfer to the structure was taken into account by adopting a load model in which the pressure of a single concentrated force N is replaced by three forces at intervals of 0.5 m and weighting factors N/4, N/2, N/4. The forward motion of the load was assumed in steps of $\Delta x = 0.02$ m. Based on this the size of the time step was determined as $h = \Delta t = \Delta x/v$. The layout of the pick-up points is shown in Figure 7.

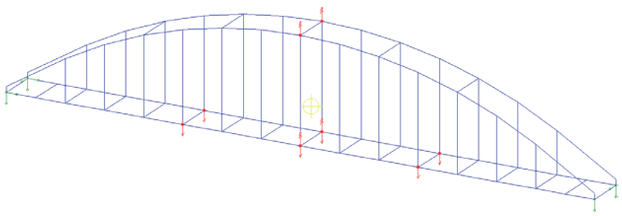


Fig. 7. Location of recording points

Tables 3 and 4 show the maximum values of deflections and accelerations of points obtained for the considered travel speeds of the ES64U4 and Pendolino trains. On this basis, the values of dynamic coefficients were determined for the tested quantities. Figures 8-17 shows the dynamic response of selected points – vertical deflections of points at one quarter and one half of the span under the right girder and vertical accelerations at the upper and lower end of the hanger in the middle of the span.

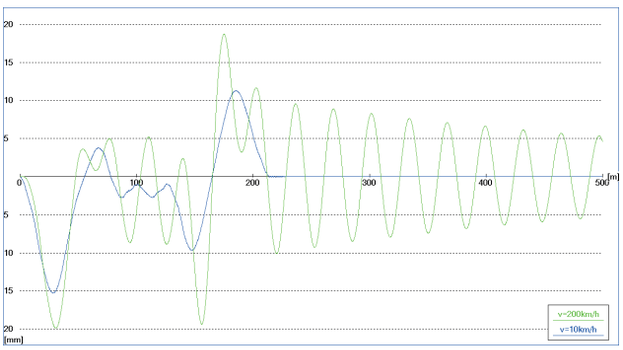


Fig. 8. Dynamic runs of the vertical displacement of the UzP3 point at the speed of 10 and 200 km/h for the ES64U4 train

Table 3. Displacements and accelerations of selected points for different speeds of the ES64U4 train

Velocity [km/h]	Displacements [mm]						Accelerations [m/s²]			
	UzP3	UzP7	UzP11	UzL3	UzL7	UzL11	PzP7D	PzP7G	PzL7D	PzL7G
static	15.27	9.15	15.21	15.27	9.17	15.21	–	–	–	–
10	15.28	9.16	15.27	15.28	9.16	15.27	0.01	0.03	0.01	0.03
40	15.26	9.26	16.24	15.26	9.28	16.3	0.08	0.15	0.07	0.15
80	15.36	9.31	16.17	15.34	9.25	16.22	0.06	0.06	0.06	0.07
120	16.14	9.38	17.31	16.14	9.42	17.34	0.15	0.13	0.17	0.14
160	17.41	9.70	19.92	17.39	9.56	20.07	0.28	0.28	0.25	0.26
180	21.00	9.60	25.30	20.86	9.78	25.47	0.26	0.27	0.27	0.31
200	19.89	10.00	21.19	19.87	9.96	21.44	0.32	0.33	0.33	0.35
dynamic coefficient	1.38	1.09	1.66	1.37	1.09	1.67	–	–	–	–

Table 4. Displacements and accelerations of selected points for different speeds of the ETR610 Pendolino train

Velocity [km/h]	Displacements [mm]						Accelerations [m/s²]			
	UzP3	UzP7	UzP11	UzL3	UzL7	UzL11	PzP7D	PzP7G	PzL7D	PzL7G
static	10.51	5.95	10.51	10.51	5.95	10.51	–	–	–	–
10	10.51	5.95	10.51	10.5	5.95	10.51	0.01	0.06	0.02	0.05
200	11.15	6.92	11.61	11.18	7.02	11.73	0.48	0.53	0.5	0.55
230	10.29	7.18	10.20	10.28	7.17	10.21	0.54	0.6	0.52	0.6
250	11.21	10.15	10.83	11.18	10.12	10.87	1.49	1.54	1.5	1.54
dynamic coefficient	1.07	1.71	1.10	1.06	1.70	1.12	–	–	–	–

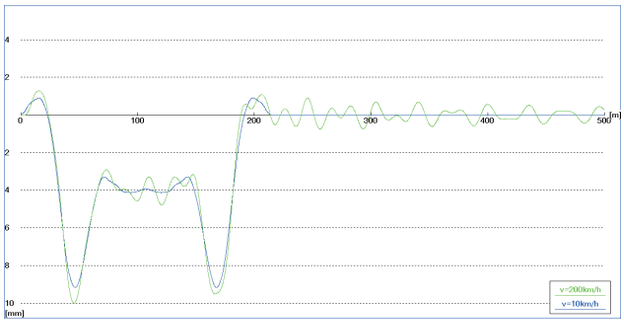


Fig. 9. Dynamic runs of the vertical displacement of the UzP7 point at the speed of 10 and 200 km/h for the ES64U4 train

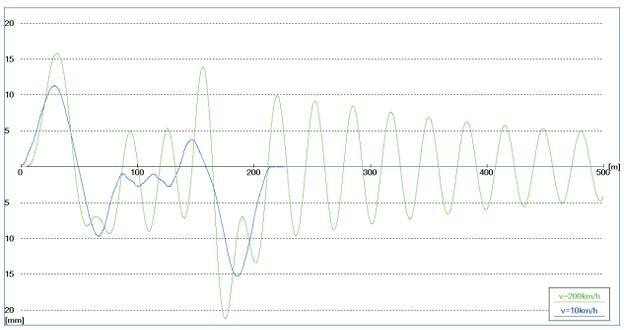


Fig. 10. Dynamic runs of the vertical displacement of the UzP11 point at the speed of 10 and 200 km/h for the ES64U4 train

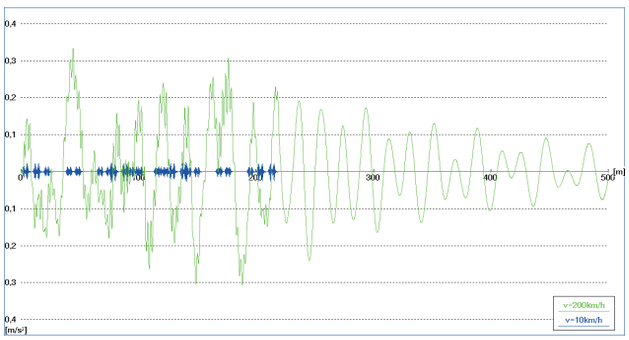


Fig. 11. Dynamic runs of the vertical acceleration of the PzP7G point at speeds of 10 and 200 km/h for the ES64U4 train

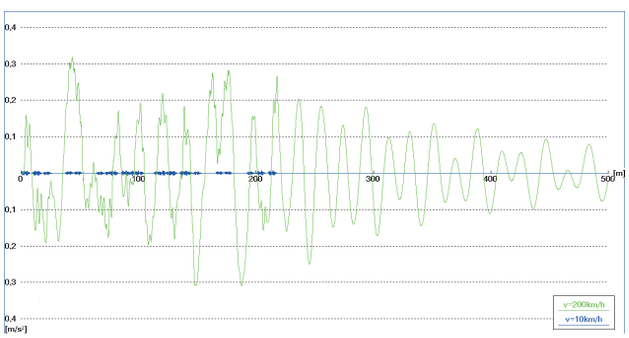


Fig. 12. Dynamic runs of the vertical acceleration of the PzP7D point at speeds of 10 and 200 km/h for the ES64U4 train

Analyzing the displacement diagrams for the ES64U4 train (Figs. 8-10), it can be seen that the impact of dynamic load for the extreme points (UzP3, UzP11) is much greater than for the middle point (UzP7). After removing the load from the bridge, the extreme points perform free damped vibrations, for the middle point they are more c omplex. The acceleration diagrams of the upper and lower ends of the PzP7 hanger (Figs. 11, 12) have a similar shape and similar values. However, their nature is slightly different. In the upper belt there are definitely larger oscillations. This is related to the lower stiffness of the arch girder in relation to the stiffness of the deck.

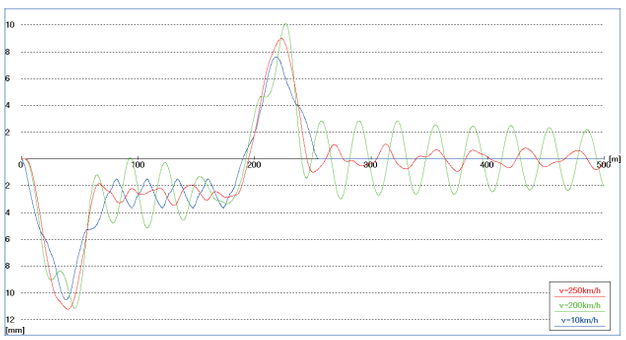


Fig. 13. Dynamic runs of the vertical displacement of the UzP3 point at speeds of 10, 200 and 250 km/h for the ETR610 Pendolino train

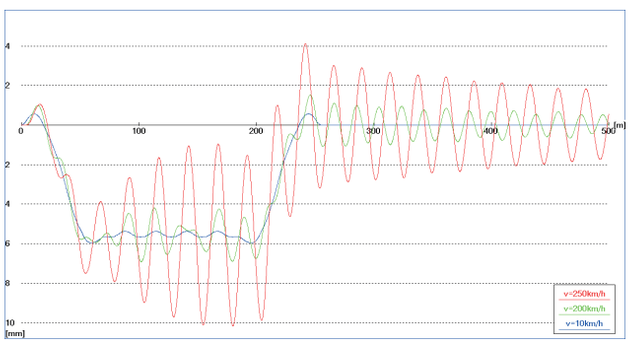


Fig. 14. Dynamic runs of the vertical displacement of the UzP7 point at speeds of 10, 200 and 250 km/h for the ETR610 Pendolino train

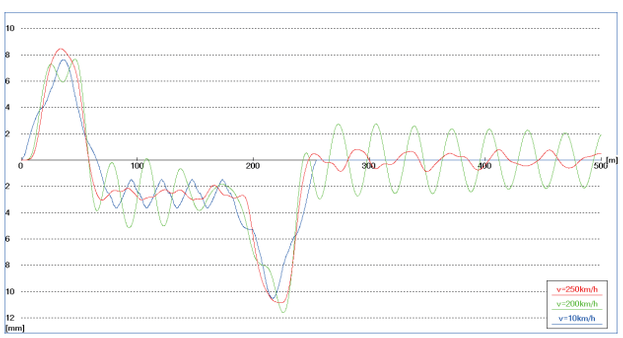


Fig. 15. Dynamic runs of the vertical displacement of the UzP11 point at speeds of 10, 200 and 250 km/h for the ETR610 Pendolino train

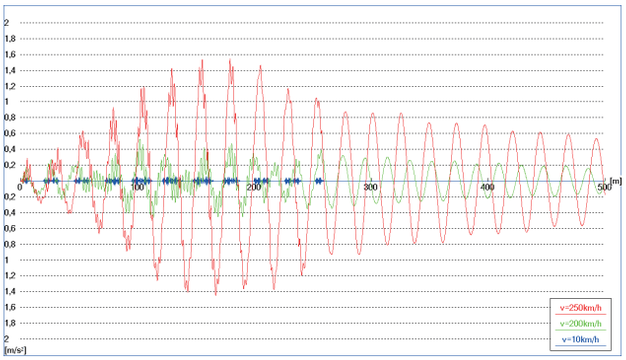


Fig. 16. Dynamic runs of vertical acceleration of the PzP7G point at speeds of 10, 200 and 250 km/h for the ETR610 Pendolino train

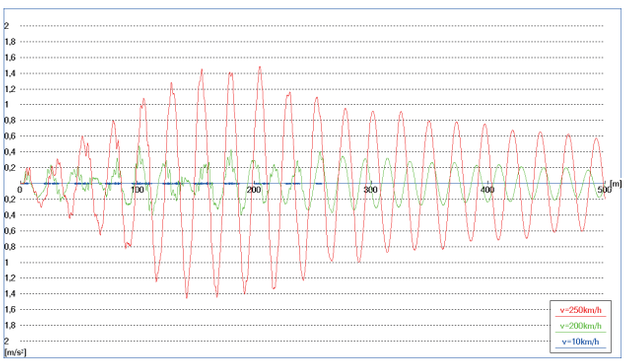


Fig. 17. Dynamic runs of vertical acceleration of the PzP7D point at speeds of 10, 200 and 250 km/h for the ETR610 Pendolino train

When traveling with the Pendolino train (Figs. 13-15), the displacements for the analyzed points are comparable to those of the ES64U4 train, except for the midpoint for the speed of 250 km/h, where we can observe much greater dynamic effects. For the Pendolino load for speeds of 10 and 200 km/h, the acceleration values (Figs. 16, 17) are similar to those for the ES64U4 train. A significant increase occurs at a speed of 250 km/h. However, the obtained acceleration values are acceptable both in terms of travel safety and travel comfort.

Comparing the ES64U4 and Pendolino trains, we can observe slightly different dynamic effects in the structure. This is related to the geometry of the bridge and the distribution of loading forces. In the case of the Pendolino train, the values of the forces are the same, in the ES64U4 train, the locomotive forces are about 1.74 times greater than those of the wagons. This results in greater changes in deflections, and consequently also vibrations, when the locomotive approaches or exits the structure. The obtained values of dynamic coefficients for individual measurement points (Tables 2 and 3) are characterized by high variability, they range from 1.06 to 1.71. There is no proportional relationship between their value and the load speed. Even for the same measurement point (e.g. UzP7) for crossings of different types of trains, the dynamic coefficient reaches the values of 1.09 or 1.71.

4. CONCLUSIONS

Railway infrastructure facilities are highly exposed to dynamic factors. With the development of computer tools, numerical simulations of such structures have become possible. Modal analysis is one of the simplest to perform, here it was carried out in the Autodesk Robot program for various variants of the mass distribution. In the case of the considered object, it was more convenient to use a discrete distribution, thus avoiding the inclusion of frequencies associated with local vibrations of individual elements, and not the structure as a whole. For both mass models, the basic vibration frequencies were similar. In the case of this type of objects, however, it can be difficult to assess the vibration mode shapes as it is not always possible to clearly determine whether it is a pure bending or torsional or other mode. The modes are usually clear only for the first couple of frequencies. In the case of the analyzed structure, the first natural frequency in an out-of-plane bending mode was equal to 1.1 Hz, and that of in-plane bending vibrations was 2.12 Hz. The first torsional mode was found at 2.44 Hz. Operational tests were carried out for this structure by the Road and Bridge Research Institute in Kielce. The results obtained were similar, which proves the correctness of the built model [29].

According to the PN-EN standards [30-35], the knowledge of the first frequencies of bending and torsional vibrations enables the decision to perform a dynamic analysis. This analysis was made using the MES3D program for two trainsets. The values of displacements and accelerations for the adopted measurement points were examined. The obtained maximum values of vertical accelerations do not exceed the value of 1.6 m/s^2, so they are within the range allowed by the standard, both in terms of travel comfort and traffic safety.

When designing the superstructure, we often use the standard dynamic coefficient. However, it has a global character and is not directly related to the velocity of the load nor does it always correctly reflect the behavior of individual parts of the structure. The values of dynamic coefficients obtained here for some measurement points are relatively high. Nonetheless, these coefficients are local and do not suggest a threat to the safe operation of the structure.

Analyzing the results presented in Tables 3 and 4, it appears that the dynamic effects do not always increase proportionally to the increase in speed.

It should also be clearly emphasized that the results of numerical calculations, especially dynamic ones, are not always consistent with the results of tests carried out on real objects, discrepancies may result from errors and imperfections in modeling the structure and load, description of damping, etc., therefore they should be supported by operational tests.

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APPLICATION OF DEEP LEARNING TECHNIQUES IN IDENTIFICATION OF THE STRUCTURE OF SELECTED ROAD MATERIALS

ZASTOSOWANIE TECHNIKI GŁĘBOKIEGO UCZENIA DO IDENTYFIKACJI STRUKTURY WYBRANYCH MATERIAŁÓW DROGOWYCH

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Juraj Šrámek
University of Zilina, Slovakia

Abstract

In research, there is a growing interest in using artificial intelligence to find solutions to difficult scientific problems. In this paper, a deep learning algorithm has been applied using images of samples of materials used for road surfaces. The photographs showed cross-sections of random samples taken with a CT scanner. Historical samples were used for the analysis, located in a database collecting information over many years. The deep learning analysis was performed using some elements of the VGG16 network architecture and implemented using the R language. The learning and training data were augmented and cross-validated. This resulted in the high level of 96.4% quality identification of the sample type and its selected structural features. The photographs in the identification set were correctly identified in terms of structure, mix type and grain size. The trained model identified samples in the domain of the dataset used for training in a very good way. As a result, in the future such a methodology may facilitate the identification of the type of mixture, its basic properties and defects.

Keywords: deep learning, tomograph, R programming language, classification, road surfaces, correlation, digital image

Streszczenie

W badaniach naukowych obserwuje się coraz większe zainteresowanie wykorzystaniem sztucznej inteligencji do poszukiwania rozwiązań trudnych problemów naukowych. W niniejszym artykule został zastosowany algorytm głębokiego uczenia z użyciem obrazów próbek materiałów wykorzystywanych do budowy nawierzchni drogowych. Fotografie przedstawiały przekroje losowych próbek wykonane za pomocą tomografu komputerowego. Do analizy wykorzystano próbki historyczne, znajdujące się w bazie danych zbierającej informacje z wielu lat. Analizę głębokiego uczenia wykonano przy użyciu niektórych elementów architektury sieci VGG16 i zaimplementowano, stosując język R. Dane uczące oraz treningowe poddano augmentacji oraz walidacji krzyżowej. W rezultacie uzyskano wysoki poziom 96,4% jakości identyfikacji rodzaju próbki oraz jej wybranych cech strukturalnych. Fotografie w zbiorze identyfikacyjnym zostały poprawnie zidentyfikowane pod względem struktury, typu mieszanki oraz uziarnienia. Wytrenowany model w bardzo dobry sposób zidentyfikował próbki w obszarze dziedziny trenowanego zbioru danych. W rezultacie taka metodyka może w przyszłości ułatwić identyfikację rodzaju mieszanki, jej podstawowych właściwości oraz defektów.

Słowa kluczowe: głębokie uczenie, tomograf, język programowania R, klasyfikacja, nawierzchnie drogowe, korelacja, obraz cyfrowy

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1. INTRODUCTION

Mineral-asphalt composites are used in the design of new road surface structures, but so are other cement-bonded materials [1]. Among these, recycled materials using both asphalt binder and cement have their well-deserved place [2]. These are materials used in deep recycling technology. Each of these materials has a different structure. It is mainly due to the presence of different aggregates as well as the way the mastic or mortar phase is shaped. Deep recycling technology is definitely dominated by recycled aggregate (RAP) [3]. In contrast, mineral and asphalt mixtures (mma) are dominated by crushed aggregate, with a crushing coefficient of $C_{90/3}$, which is required primarily to ensure that the mma has an adequate internal friction coefficient. In contrast, cement-bound mixtures for substructures as well as soil-cement stabilisations have a structure similar to cement concrete [4] taking into account the macrostructure of the pavement layers, which are made of heterogeneous materials. The interaction between the joined layers was determined by applying a cohesion contact model. The parameters of the model were identified using the results obtained in the course of the actual Leutner tests. The heterogeneity of the structure was mapped based on a digital image of a tomographic cross-section. The separation of the materials included in the individual layers was performed with the use of a script in the MatLab program. Thanks to this, the batch file for the Abaqus program was prepared thoroughly. As a result, it was possible to map as closely as possible the profile of the deformation caused by the loss of the interlayer adhesion. Based on the data analysis, it was found that in the layer of the base course constructed from cold-applied recycled materials, the loss of interlayer adhesion is related to the state of non-linear mastic deformation. As a consequence, it was found that large deformations in the mastic structure would cause losses of aggregate grains in the recycled layer. In addition, a large horizontal displacement within the layer of the base course made of recycled material is one of the likely causes of edge fractures in the road structure.”,”container-title”:”Structure and Environment”,”DOI”:”10.30540/sae-2021-011”,”ISSN”:”20811500”,”issue”:”4”,”journalAbbreviation”:”SAE”,”source”:”DOI.org (Crossref. These differences suggest that it is possible to find relationships from which a preliminary diagnosis can be made in terms of material quality as well as potential defects in the structure.

To some extent, this problem can be solved by using shallow machine learning techniques. Such data mining techniques (Data Mining) are so far applied, but they are mainly used to correctly predict the mechanical or physical properties of road materials. The undoubted advantage of Data Mining methods is the inclusion of both qualitative and quantitative variables. In their paper, Rebelo et al. [5] used a number of DM techniques to effectively predict the water resistance of mineral-asphalt mixtures. Whereas in the paper [6] the authors have used DM to improve road surface rutting resistance. In their work, Guo and Hao [7] used a random forest algorithm to assess road surface durability using information on emerging damage. The estimation of the stiffness modulus was successfully determined using Falling Weight Deflectometer (FWD) and with the aid of an artificial neural network (ANN) or support vector machines (SVM) [8, 9]. DM techniques have also excelled in predicting IRI [10] however, limit the implementation of ML by practitioners and transportation agencies. One of these challenges is related to the high variability in the performance of ML models as reported by different studies and the lack of quantitative evidence supporting the true effectiveness of these techniques. The objective of this paper is twofold: to assess the overall performance of traditional and ML techniques used to predict pavement condition, and to provide guidance on the optimal architecture and minimum sample size required to develop these models. This paper analyzes three ML algorithms commonly used to predict International Roughness Index (IRI) or skid resistance [11].

However, the best technique to solve this complex problem that is beyond the perception of the observer’s senses is deep learning using convolutional networks. At the present time, this type of analysis is being successfully used especially in medical diagnostics [12]. Nevertheless, it also finds use in civil engineering. The road industry has recently seen the emergence of preliminary analyses using deep learning to identify the condition of road surfaces. This approach makes it easy to identify damage and perform a quick classification of road surface condition “on the fly” by analysing images taken with a smartphone [13]. It can also support the identification of particularly damaged sections of road surface [14]. However, it should be made clear that it is difficult to find attempts in the literature to use a deep learning (DL) algorithm to recognise the structure of road materials from tomograph-derived images. The level of abstraction of the input data suggests that other methods will not

be effective for the intended purpose. The search for similarities through image decomposition requires the consideration of several million indeterminates, which clearly disqualifies an analytical approach using, for example: logistic regression or DM. An additional advantage of using DL is that it not only looks for similarities in the contours of objects, but also for changes in their colour.

The aim of the research and analysis performed was to determine the scale of the feasibility of implementing DL to identify the structure of selected road materials. The paper also considers the possibility of looking for correlative relationships between the identified objects and selected physical characteristics of road composites. This article should be regarded as a feasibility study of the implementation of a current state-of-the-art learning technique for road applications.

2. MATERIALS AND METHODS

2.1. Deep learning

As already mentioned, a technique frequently used for classification and regression tasks is the shallow learning technique. With its help, a number of scientific problems can be solved. However, in order to do this, steps must be taken to process the features, i.e. to create appropriate layers of data representation. In deep machine learning, this step is automated. This facilitates the entire workflow and is therefore most suitable for processing complex objects such as digital images.

Deep learning involves the application of multiple successive layers of representation. This is a technique that works very well when working on perceptual tasks. In the case of shallow learning, the addition of subsequent steps leads to less and less improvement in the results obtained [17]. This is because the optimal first layer of the representation is not the optimal layer of the multilayer model. In deep learning, it is possible to combine all layers of data representation. In other words: modifying one internal feature of the model results in automatic adaptation of the entire model without the need for user intervention. This change is controlled by a single feedback signal. For shallow machine learning models, it is not possible to correctly describe multiple relationships in objects with a high level of abstract representation without the need to add subsequent intermediate layers (independent of each other).

At the present time, deep learning involves the creation of dozens of successive representations learned from training data, compared to shallow learning which usually contains two layers of representations. Although deep learning was developed for classification tasks involving object-image mapping using a deep sequence of simple transformations, the DL technique can be used successfully for regression tasks. The issue that needs to be changed is a different algorithm for tuning the weights, i.e. the optimiser, and a different form of the objective function (loss function). A loss function is nothing more than the distance between the predicted value and the actual value. In the case of an image, it denotes the accuracy of the image processing by the network. Far more important is the selection of the optimiser, i.e. the backpropagation algorithm. It is directly responsible for the efficiency in tuning the weights of the transformation function which directly translates into the efficiency of the representation of the output results. As a result, the operation of the deep learning algorithm can be represented by the nomogram in Figure 1.

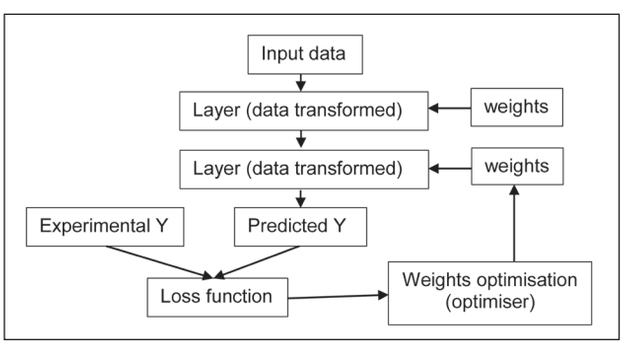

Fig. 1. Convolution network diagram

A network with minimal loss can be considered trained, which translates into a high representation of the test object. In essence, DL can be thought of as a multi-stage operation of "distilling" information passing through successive "filters", producing increasingly clear and homogeneous results. The key to achieving high efficiency is proper management of the weights (Fig. 1). The weights are a set of numbers that allow the data transformation to be performed in such a way that the process of mapping predicted data sets to experimental ones is as accurate as possible. Therefore, in deep learning, a network can contain millions of parameters. A key element that has made DL techniques more affordable is the availability of efficient optimisers and the calculational capacity of numerical machines. The calculation time involved in fine-tuning the weights is fast and the efficiency is far better than traditional methods such as logistic regression.

2.2. Convolutional network architecture

This paper uses elements of the VGG16 convolutional network architecture trained on the ImageNet set [18]. The ImageNet set included 1.4 million images divided into 1,000 classes. The present network was trained on a very general set and had a correctness of object identification of >96%. Thus, the learned spatial hierarchy of features can effectively form the basis for identifying the structure of road materials assigned to classes not included in the ImageNet set. The ability to transfer the "knowledge" contained in pre-trained networks to other sets is a huge advantage over shallow learning methods. The VGG16 network was used for the analysis using the technique of extraction of features of interest. These features are then processed by a new classifier, which in this paper will be subjected to a process of training from scratch. This network will consist of pooling and convolution layers. The final stage is the densely connected classifier mentioned earlier. Indeed, the convolutional part of the network consists of the overall rule and image recognition concepts. The convolutional part can be shared, while the dense classifier is directly related to the specifics of the object, in this case a photograph taken via a road material tomograph.

Given the above assumptions, the concept and architecture of a trained convolutional network will be used, applying a feature extraction technique in the process. A new final classifier will then be trained from scratch. The use of the VGG16 trained convolutional network will allow the use of generalisations in image interpretation that have proven successful for identifying ImageNet set objects. The abbreviated architecture of the VGG16 network is given below (Table 1).

Table 1. Abbreviated form of the convolutional architecture of the VGG16 network

Layer (type)	Output Shape	Param#
Input_1 (InputLayer)	(None, 150,150,3)	0
block1_conv1 (Conv2D)	(None, 150,150,64)	1792
block1_conv2 (Conv2D)	(None, 150,150,64)	36928
block1_pool (MaxPooling2D)	(None, 75,75,64)	0
(…)		
block5_conv1 (Conv2D)	(None, 9,9,512)	2359808
block5_conv2 (Conv2D)	(None, 9,9,512)	2359808
block5_conv5 (Conv2D)	(None, 9,9,512)	2359808
Block5_pool (MaxPooling2D)	(None, 4,4,512)	0
Total params: 14,714,688 Trainable params: **14,714,688**		

The final feature map of the VGG16 network to be used for further analysis was (4,4,512). The next step was to extend the model, as previously conceived, to include dense classifier layers. The downside of this procedure is the long costly calculation time, which depends on the performance of the processor. On the other hand, an indisputable advantage of this technique is the use of "data augmentation", which is essential when there is a small input data set. The problem presented in this paper was solved using a sequential model, linking successive network layers. The final network model was as follows (Table 2).

Table 2. Abbreviated form of the convolutional architecture of the VGG16 network

Layer (type)	Output Shape	Param#
VGG 16 (previous model)	(None, 4, 4, 512)	1,471,4688
Flatten_1 (Flatten)	(None, 8192)	0
dense_3 (Dense)	(None, 256)	2,097,408
dense_4 (Dense)	(None, 1)	257
Total params: 16,812,353 Trainable params: **16,812,353**		

The added dense classifier required to obtain a measurable value for the class similarity scale of a given photograph introduced an additional 2 million parameters over the baseline VGG16, so the final model included a total of more than 16 million parameters. Therefore, the process of training the network had two-stages. Initially, it was necessary to freeze the VGG16 network for the duration of the dense classifier training. In the next stage, part of the VGG16 network blocks were unfrozen. This will provide greater control over the changes in the "knowledge" that the VGG16 convolution network brings.

2.3. Examination by means of computed tomography

Computed tomography is a non-destructive technique used to analyse the internal structure of materials based on the properties of X-rays. One of these properties is the ability to travel through matter, losing energy on the way according to Beer's law. The incidence of linear attenuation μ depends on the density of the material under examination at each point through which the beam passes. The creation of a tomographic image is based on measuring the absorption of radiation by an object. Performing a scan in a CT scanner is based on directing a beam of X-rays at an object and then recording its intensity through a detector on the other side of the object.

The study uses a composite of object projections taken from different directions to generate two-dimensional (2D) cross-sectional images and then three-dimensional (3D) models. The scanned object is divided into small cells, called voxels (*volumetric element*, equivalent to a pixel for a 2D image), for which the linear absorption coefficient is the same. A the tomograph operating diagram is shown in the figure below (Fig. 2).

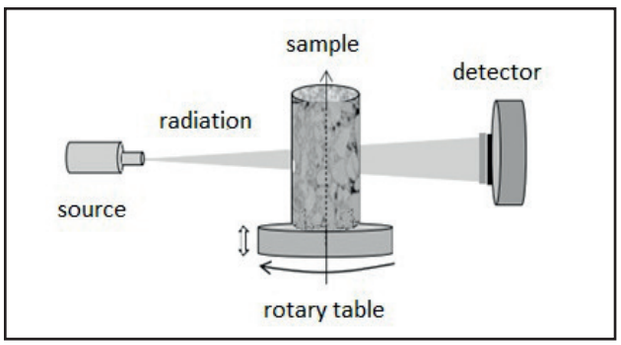

Fig. 2. Tomograph operating diagram [19]

Scanning is performed by exposing the object to X-rays while rotating the sample 360° relative to a stationary tube and detector. The accuracy of the final representation depends on the number of projections made during the object's rotation. By having projection images for multiple cross-sections of the object, the image of the entire sample is reconstructed using the Radon transform. The practical result is a three-dimensional greyscale image in which each shade of grey corresponds to a specific density value. Lighter tones represent higher densities, while darker tones denote lower density materials.

The study was performed on a Nikon XT H 225 ST CT scanner. A rotating lamp generating a beam of radiation with a maximum voltage of 225 kV and a power of 450 W was used. When performing the scans, the voltage and intensity values used were selected experimentally, by scanning the sample several times, to ensure the best possible parameters for the type of material. From the combination of almost 4,500 images, a 3D model of the object with a resolution of at least 84 µm was created. This was achieved by reconstructing the data and pre-processing it, determining the axis of rotation, reducing noise, sharpening edges and applying filters in CT Pro 3D.

2.4. Research sample

The set of photographs of the various materials used for incorporation into the road structure included 260 photographs. All photographs were divided into 14 classes. Each class represented one object with characteristics that differed from each other. The following types of road materials found in the archival research database constituted the set of selected objects (Table 3).

Table 3. Identification and description of object classes

No.	Class	Description
1.	CC(G)	Cement concrete 0/16 containing, among other things, granite aggregate
2.	AC11(Ga)	0/11 asphalt concrete containing, among other things, gabbro aggregate
3.	WMS_I	0/16 asphaltic concrete with a high stiffness modulus with limestone aggregate.
4.	MCAS_I	Recycled mix of foamed asphalt with a fine-grained structure with the addition of road binder C5 [20]
5.	AC16_PMB	Asphalt concrete 0/16 containing modified asphalt for the wearing course
6.	AC22P	Asphalt concrete for sub-base with a maximum grain size of 22 mm
7.	WMS_II	0/16 asphalt concrete with a high stiffness modulus
8.	AC8S	Asphalt concrete with a grain size of 0/8 for the wearing course
9.	MCE	Cement & emulsion mixtures for incorporation into the sub-base layer in deep recycling technology
10.	MMP	0/16 mm mineral-emulsion-polymer mix with dispersed powders
11.	MCAS_II	Recycled mix with foamed asphalt containing limestone aggregate
12.	CBGM_CEMI	A soil-cement mixture designed for a sub-base layer with a cement content of 4%
13.	CBGM_CEMI_M	A soil-cement mixture containing metakaolin designed for an auxiliary sub-base layer with a cement content of 4%
14.	CBGM_PK	A soil-cement mixture containing bark ash designed for an auxiliary sub-base layer with a cement content of 4%

The sample set was randomly divided into two subsets with the following percentages:

- learning – 70%,
- test – 30%.

In addition, an additional set of photographs with similar characteristics to the learning set was used for validation to confirm the validity and effectiveness of the DL technique used. A subset of the learning data was selected so that the number of data in the classes and their types were as equivalent as possible.

3. ANALYSIS OF RESEARCH RESULTS

3.1. Data set augmentation

The dataset used in the analysis is not large in number, so the learning effect was enhanced by using a data augmentation technique. It consists of randomly transforming a random image in such a way as to best eliminate certain peculiarities and its initial settings and thus enhance the level of generalisation of the trained convolutional network. This procedure dismisses the possibility of fine-tuning the scales using two of the same photographs, i.e. it prevents the network from "overlearning". A code snippet with the configuration of the parameters used during data augmentation is shown below:

```
train_datagen_augmentation<- image_data_generator(
rescale=1/255,
rotation_range = 40,
width_shift_range = 0.2,
height_shift_range = 0.2,
shear_range = 0.2,
zoom_range = 0.2,
horizontal_flip = TRUE,
fill_mode = "nearest").
```

In summary, data augmentation is not about creating new data. Its task is to use existing photographs submitted for further analysis by performing a random and one-off transformation in them.

3.2. Course of the learning process

The first stage of the convolutional network learning process started by freezing the weights of the VGG16 network. In this step, only the dense classifier weights were trained. Otherwise, the training process could introduce permanent changes to the underlying convolutional network VGG16, strong enough that the resulting network would generate incorrect results. The loss function should be selected according to the scale of the problem. Therefore, a categorical crossentropy function was used. It is an optimisation function that classifies data by predicting the probability of the data belonging to one of the defined classes. On the other hand, a softmax function was used as the last class activation function together with an RMSprop optimiser with a learning rate of $1 \cdot e^{-5}$. The final result was a vector of probability values for assigning a given object to all 14 classes in the range <0;1>. In the first stage, 200 epochs were used, taking a batch of 20 photographs at a time for analysis. The result of the trained network, through the use of a validation set, achieved a concordance expressed by a coefficient of determination of $R^2 = 92.9\%$ with a value of the loss function of the learning set equalling 2.0086 and, respectively, of the test set equalling 2.0413. An increase in the value of the loss function on the test set suggested a slight overlearning of the network. Thus, further training of the dense classifier did not provide new quality (knowledge) in photograph identification. The results of the test photograph match probability are shown in Figure 3.

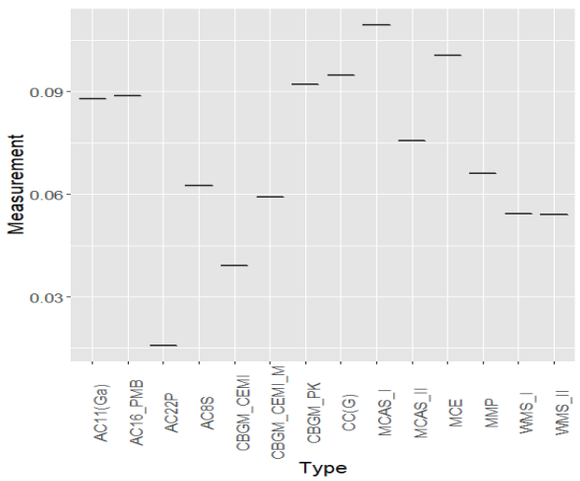

Fig. 3. Probability of an AC16W reference sample photograph belonging to a class of a trained convolutional network

Observing the results in Figure 3, it should be noted that the trained dense classifier and the frozen weights from the ImageNet set found the AC16W asphalt concrete mix similar to the MCAS_I mix (11%) or the MCE mix (10%). This is an unsatisfactory and erroneous result and further fine-tuning of the convolution network is required. This is because originally the scales in the VGG16 network architecture were used to identify objects other than road materials.

Therefore, a second phase related to the fine-tuning of the convolutional network was realised. As a result, the layers of the convolutional network were unfrozen starting from level 3 of the network shown in Table 1. Training took place, introducing another 100 epochs. This value has been set so as not to cause overtraining of the network. Once the training process was complete, the tuned model was validated by assessment of its effectiveness, using a validation set of the same model used in the first step. The effectiveness of the model, as expressed by the R^2 coefficient for the model, was 96.4%. This result should be regarded as very good. Such efficiency should be linked directly to the unfreezing of the network layers responsible

for recognising high-level detail. The improvement in the quality of the trained network increased from R^2 = 92.9% (stage 1) to R^2 = 96.4% (stage 2). Nevertheless, a tendency of the network to learn "by heart" was observed in the second phase of network training. This phenomenon is shown in Figure 4.

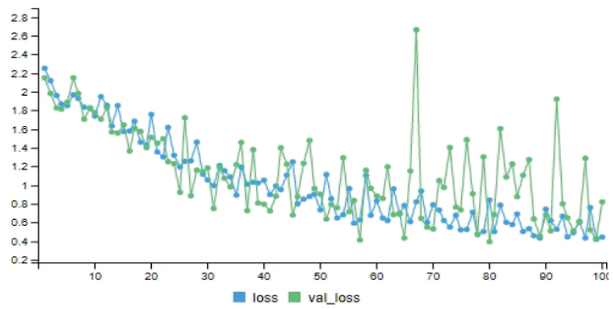

Fig. 4. Graph of the change in the loss function for the learning (loss) and test set data (val_loss)

A negligible increase in error on the test set was observed from epoch 70 onwards, while error stabilisation was observed for the learning set. In order not to cause excessive network overlearning, the number of 100 epochs should not be increased.

3.3. Validation of Results

Validation of the resulting model was subject to an assessment of the ability to identify objects (road materials) that had not been involved in previous model evaluations. Additional validation objects included photographs of the AC16W mix. The result of the AC16W classification against the defined classes is shown below (Fig. 5).

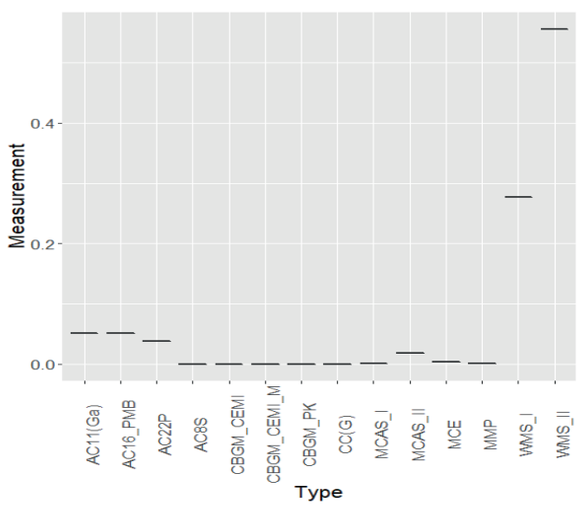

Fig. 5. Probability of the photograph of the AC16W reference samples belonging to the class of trained convolutional networks after stage two (unfreezing of selected layers)

The results of the classification by means of the trained convolutional network, shown in Figure 4, indicate that the greatest similarity of AC16W can be attributed to the WMS_I and WMS_II mix type class. This is definitely a big difference from the phase 1 results (Fig. 3). This time, the algorithm correctly indicated that the analysed samples have a concrete-type closed structure. The DL algorithm firmly disqualified recycled mixtures (MCAS/MCE) and CBGM. To give an idea of the possibility of comparison, photographs of the two mma most similar to the AC16W are juxtaposed in Figure 6.

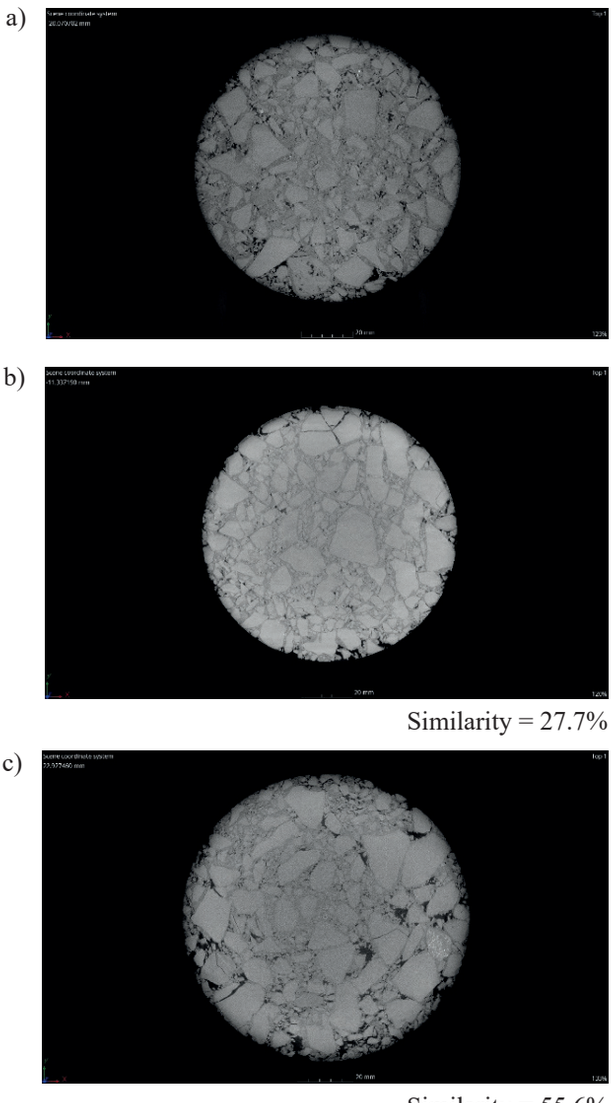

Fig. 6. Juxtaposition of the two samples with the highest similarity to the reference sample: a) reference sample AC16W, b) WMS_I, c) WMS_II

Probably the rules of similarity established by the convolution network resulted from the nature of the

mastic structure produced, the type of aggregate (grey shade) and the pore content. In addition, the grain size, i.e. the dimension of the maximum grain, can also be expected to have made a difference. In the cases analysed (Fig. 6) the grain size curve was 0/16. It turned out that the convolutional network can, with a small set, correctly classify objects with significantly different embedding technology. CBGM and recycled MCE/MCAS mixes are used for the substructure. On the other hand, type WMS or classic AC with concrete structure are used for the upper structural layers. In view of the facts cited, a measurable probability value can be linked to physical characteristics in the future, e.g.: water resistance of the mma.

In the future, it is planned to superimpose heat maps [21], which will allow the key area of the convolutional network to be highlighted, from which it can be determined what caused the sample to be classified in this way. Thus, it will be possible to identify areas in the structure of the material used in road construction which should be analysed in detail, focusing on the reasons for a particular regularity in its structure.

4. CONCLUSIONS

Based on the research and analysis performed, the following conclusions were formulated:

- the use of convolutional network algorithms is an excellent tool for classifying abstract objects of a perceptual nature;
- the use of modifications to the available architecture of other convolutional networks allowed the correct identification of the composite in terms of grain size, type, manufacturing technology and structure;
- the use of data augmentation and the unfreezing of the deep layers of the convolutional network dramatically increased the ability to identify objects from R2 = 92.9% to R2 = 96.4%;
- based on the set of photographs, the network, with a level of concordance of R2 > 96%, correctly classified the AC16W as regards structure, mix type, grain size and colour of the aggregate.

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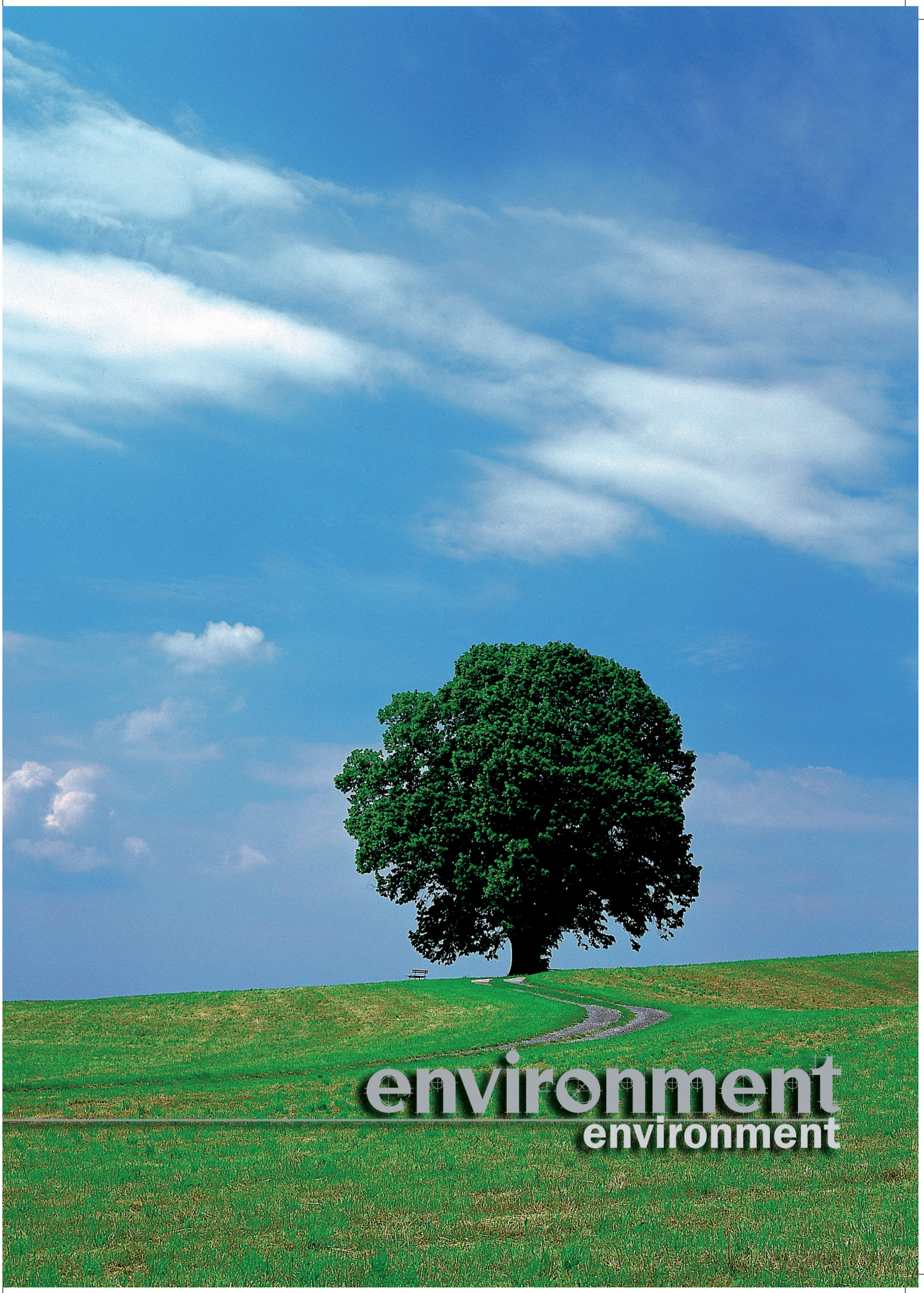

environment

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ASSESSING THE FINANCIAL BENEFITS OF USING A SHOWER DRAIN HEAT RECOVERY SYSTEM – A CASE STUDY

OCENA KORZYŚCI FINANSOWYCH Z WYKORZYSTANIA INSTALACJI ODZYSKIWANIA CIEPŁA Z ODPŁYWU SPOD PRYSZNICA – STUDIUM PRZYPADKU

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Abstract

The production of hot water for bathing in Poland accounts for around 15% of the total energy consumption of a typical household. According to EU data, final energy consumption for lighting and appliances is similar to final energy consumption for hot water preparation. This makes it a significant contributor to housing and utility costs, exceeded only by heating expenses. Research has indicated that only about 10% of the water utilized during a shower is necessary for hygiene purposes. Consequently, around 90% of the hot water supplied to the shower is ultimately discharged into the sewage system. By harnessing the primary energy from wastewater, we can effectively conserve heat energy and reduce the overall expenditure associated with hot water. The objective of this article is to explore the utilization of heat recovery from domestic wastewater as a means to enhance the energy efficiency of residential buildings.

Keywords: wastewater heat recovery, grey wastewater, heat exchangers

Streszczenie

Wytwarzanie ciepłej wody w Polsce do kąpieli stanowi około 15% całkowitego zużycia energii w typowym gospodarstwie domowym. Według danych UE, końcowe zużycie energii na oświetlenie i urządzenia jest zbliżone do końcowego zużycia energii na przygotowanie ciepłej wody użytkowej. To sprawia, że jest to znaczący czynnik wpływający na koszty mieszkaniowe i użytkowe, przewyższany jedynie przez wydatki na ogrzewanie. Badania wykazały, że tylko około 10% wody zużywanej podczas kąpieli pod prysznicem jest niezbędna do celów higienicznych. W rezultacie około 90% ciepłej wody dostarczanej do prysznica jest ostatecznie odprowadzane do kanalizacji. Wykorzystując energię pierwotną ze ścieków, możemy skutecznie oszczędzać energię cieplną i zmniejszyć ogólne wydatki na ciepłą wodę. Celem tego artykułu jest zbadanie wykorzystania odzysku ciepła ze ścieków domowych jako sposobu na zwiększenie efektywności energetycznej budynków mieszkalnych.

Słowa kluczowe: odzysk ciepła ze ścieków, ścieki szare, wymienniki cieplne

1. INTRODUCTION

An analysis of total primary energy consumption in buildings has shown that the percentage of energy consumption for heating hot water is approximately 15% [1]. With continued efforts to reduce energy consumption for heating buildings, the percentage of energy consumed for heating water by hot water supply systems will increase every year. The huge

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amount of heat energy contained in wastewater is usually not used but simply discharged into the sewer system. To meet European climate protection targets, the use of heat from wastewater provides a huge and largely untapped potential for the development of a cost-effective heat supply for buildings [2].

The idea of extracting heat from wastewater by means of heat pumps is not new. Since the 1980s, centralized systems in Germany, Switzerland, Sweden or Norway have been using the heat from wastewater collected in sewers and in treatment plants [1]. The temperature of the wastewater at the collection points is from 10-15°C all year round, and reaches up to 20°C in summer, which is sufficient for guaranteed and uninterrupted operation of the heat pumps. In the winter months, when there is a high heat demand, the wastewater temperature at the centralized heat pump sites is only around 10°C, which reduces the efficiency of the heat pump [3].

There are four main possible locations for heat recovery from wastewater in a sewerage system [4]: at the sanitary level (A), at the building level (B), in the sewer pipe network (C) and from the sewage treatment plant (D). The main and most economical and most common option is variant (A).

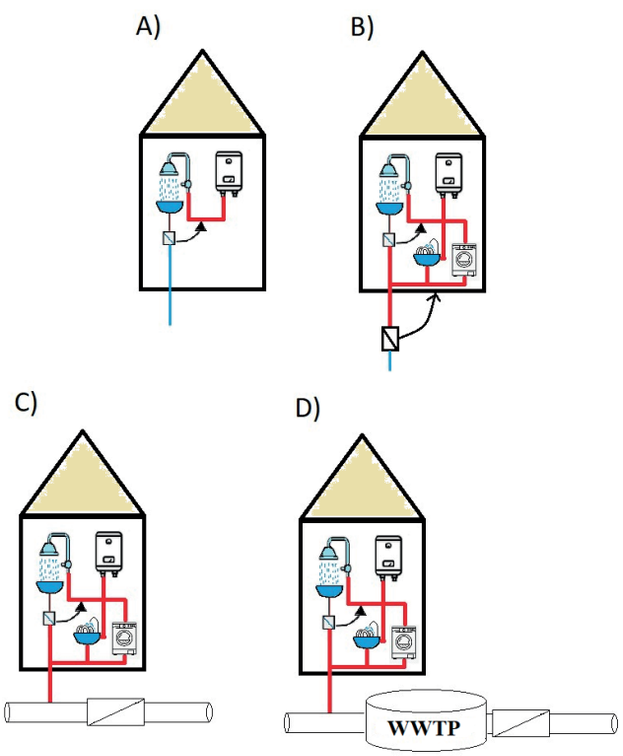

Fig. 1. Possible options for heat recovery from wastewater [4]

At the sanitary appliance level, heat is recovered from waste water immediately after it is generated during specific single-factor activities (e.g. showering, cooking, eating). The heat is recovered using a heat exchanger directly downstream of the sanitary appliance in question. The recovered heat can be used to pre-heat the feed water, in domestic or commercial shower installations.

Heat recovery from shower water is the most common application found in practice. The advantage of this application is the continuous, simultaneous counter-current flow of wastewater and cold water supply to the shower. Heat recovery in this case, can be realized with high efficiency, and in addition, there is no time delay between the availability of waste heat and the heat demand for showering, eliminating the need for heat storage and the resulting losses [5, 6].

A general scheme for heat recovery from shower water is shown in Figure 2.

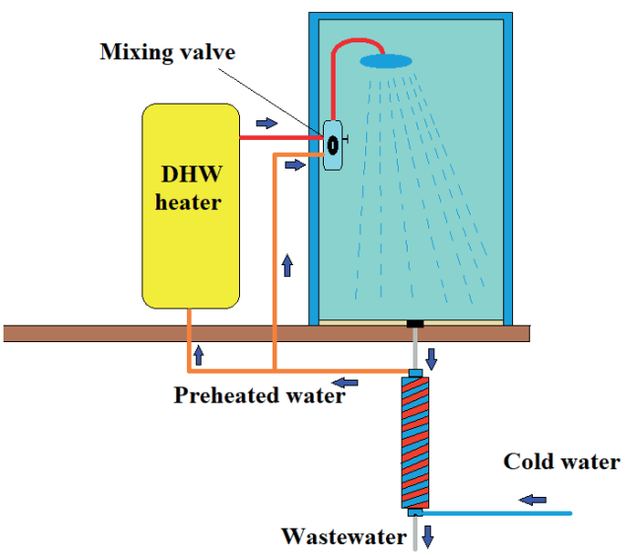

Fig. 2. Schematic of heat recovery from under the shower (own research)

2. MATERIALS AND METHODS

The studies analyzed in this document, focusing on the WWHR for option A at different shower durations and different numbers of residents using the shower. In order to carry out these calculations, it was necessary to use the average water consumption data for the sanitary facilities and the water temperature at the inlet and outlet. The cost analysis was carried out in terms of investment and operating costs.

The flow rate of the grey waste water draining from the shower and the cold water drain are equal. When mixing hot water from the effluent (which is warm due to the shower) with cold water, the thermal energy transferred between the two depends on the temperature difference between them and the flow rate [7]. If the temperature difference between cold water and wastewater (ΔT) is different, the increase in the temperature of the cold water supply will be different from the decrease in the wastewater temperature. Conversely, if ΔT is equal, there will be no change in the temperature of the cold water supply.

The Building America Research benchmark definition [8] provides a general model for end-user hot water consumption, as described in Table 1. N_{br} [-] is the number of bedrooms in a dwelling. Figure 3 shows the hourly hot water consumption for each end-user as a fraction of the total end-user consumption [9].

Table 1. Hot water consumption by end use [5]

End use	End water temperature °C	Water consumption/ dm³/d
Clothes washer	49.0	$28.4 + 9.46N_{br}$
Dishwasher	49.0	$9.46 + 3.15N_{br}$
Shower	40.6	$53 + 17.67N_{br}$
Bath	40.6	$13.25 + 4.43N_{br}$
Sinks	40.6	$47.32 + 15.75N_{br}$

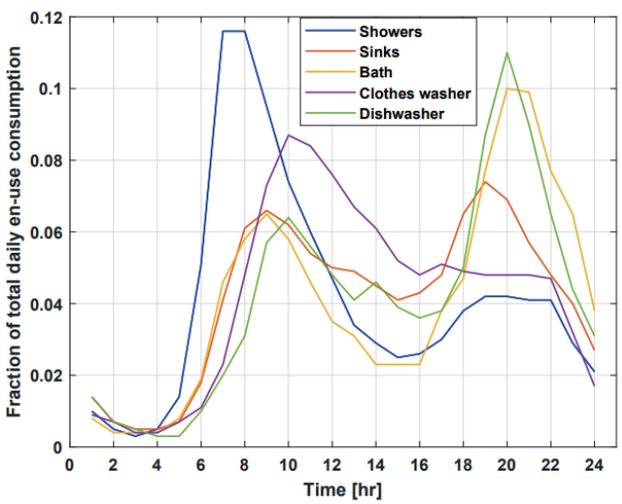

Fig. 3. Typical hot water consumption profile [5, 9]

For the selected prototype, i.e. the number of bedrooms N_{br} = 2, the total hot water consumption is approximately 250.35 m³/d based on the equations given in Table 1.

The amount of energy consumed by the DHW heater can be determined by the equation [10]:

$$W = c \cdot \Delta T \cdot q \cdot \sigma \cdot t \cdot 10^{-3} \text{ [kWh]} \quad (1)$$

where:

W – amount of energy consumed by the DHW heater during the shower [kWh];
t – duration of showering [s];
q – volumetric water flow rate heated in the heater – 0.15 dm³/s;
σ – density of water heated in the heater [kg/dm³];
c – specific heat of water heated up in heater [Wh/kg·K];
ΔT – temperature difference between cold and hot water [K];
Thw – temperature of hot water [K];
Tcw – temperature of cold water [K].

3. CASE STUDY

This paragraph presents an example of the calculation of potential financial gains using a heat recovery system for grey waste water discharged from a shower. The cost of a shower lasting 3, 5, and 10 minutes, without heat recovery, and with recovery, was analyzed. Three-phase instantaneous water heaters of 27 kW were used.

A hot water temperature of 40.6°C and a cold water temperature of 10°C was assumed. The grey waste water temperature oscillates between 35-40°C, and a value of 35°C was assumed for the calculations. Temperature-dependent water properties such as specific heat and density were assumed on the basis of tables of water physical properties [11]. The cost of electricity was determined for the average total cost of 1 kWh in Poland in 2023 for the G11 tariff group of 0.627 PLN/kWh [12]. Calculations were made for variants with two, three, and four people assuming that each person uses the shower once a day. Table 2 shows the amounts of electricity required for the operation of the heater in the two variants, for different showering times.

Table 2. Summary of the results of cost recovery calculations in the case of the use of wastewater heat recovery systems, for different variants of the duration of the shower, and the number of people using the shower

Duration of shower		3 min			5 min			10 min		
Number of people using the shower		2	3	4	2	3	4	2	3	4
Without heat recovery	kWh	1.92	2.88	3.84	3.20	4.80	6.40	6.39	9.59	12.79
	Cost [PLN]	1.20	1.81	2.41	2.01	3.01	4.01	4.01	6.01	8.02
Annual cost [PLN]		433	650	867	722	1083	1445	1442	2165	2887
With heat recovery system	kWh	0.37	0.56	0.74	0.62	0.93	1.24	1.24	1.86	2.48
	Cost [PLN]	0.23	0.35	0.46	0.39	0.58	0.78	0.78	1.17	1.55
Annual cost [PLN]		84	128	168	143	212	285	285	427	565
Annual profit with heat recovery [PLN]		349	522	699	579	871	1160	1157	1738	2322
Period in years needed to recover the investment [years]		14.3	9.5	7.2	8.6	5.7	4.3	4.3	2.9	2.15

4. RESULTS AND DISCUSSION

The amount of investment outlay was assumed to be the purchase price of the heat exchanger and the cost of its installation. The cost of such an exchanger ranges from 2000 to 4500 PLN [13], depending on the model and manufacturer. The installation price depends mainly on whether the installation will be carried out in a new or old building. For the calculations, the total investment cost for 2023 was assumed to be PLN 5,000. Figure 4 presents a graph of the annual costs of domestic hot water preparation for showers with and without heat recovery for different calculation variants.

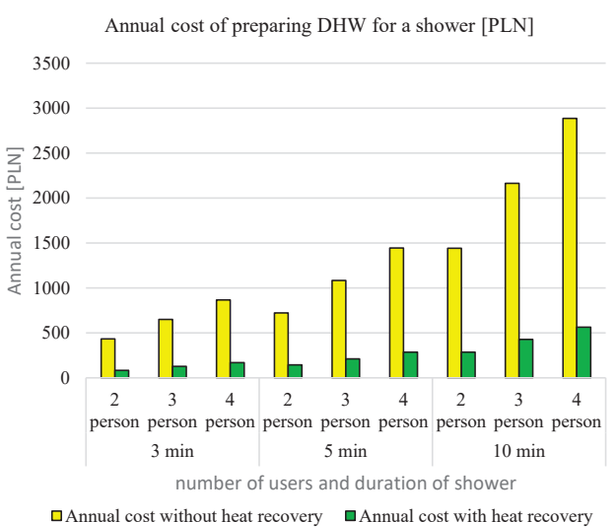

Fig. 4. Cost for shower with and without recovery [values given in PLN]

The expected annual profits from installing a wastewater heat recovery system range from approximately 349 PLN for the shortest bathing time, with two users, to 2,322 PLN per year for 10-minute baths with four users.

The calculation results presented show that the duration of the bath and the number of users have a significant impact on the financial efficiency of the project. Assuming an average shower duration of 5 minutes, the payback period for such a shower varies from about 8.5 years (2 persons) to about 4.5 years (4 persons). For long showers, on the other hand, the payback period should not exceed 4.5 years.

5. CONCLUSIONS

An analysis of the financial efficiency of using a heat recovery system from shower drain water from the shower allowed the following conclusions to be drawn:

- There is a relationship between the daily duration of the shower use and the number of users and the possible financial savings. The financial efficiency increases with increasing shower duration and water consumption. Consequently, the benefit of a heat recovery system is most cost-effective for large families, sports, service facilities and industrial facilities where showers are frequently used.
- For families of at least 4 people, with each person using the use the shower at least once a day for 5 minutes, the payback time should not exceed 5

years. The annual return for families of 4 people ranged from 699 to 2322 PLN, depending on the duration of the shower.

- Reducing DHW consumption means that less energy will be needed to heat the water, resulting in measurable savings. Furthermore, by reducing energy consumption, heat recovery systems can help reduce greenhouse gas emissions and contribute to a more sustainable future.

Overall, a shower waste heat recovery system can be an effective way to improve the efficiency and sustainability of a domestic hot water system.

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CLASSIFICATION OF SETTLEMENTS BY ECONOMIC POTENTIALS IN THE SOUTHERN REGION OF NIGER STATE: A LOCATION QUOTIENT APPROACH

KLASYFIKACJA OSAD WEDŁUG POTENCJAŁU GOSPODARCZEGO W POŁUDNIOWYM REGIONIE STANU NIGER (W NIGERII): PODEJŚCIE OPARTE NA ILORAZIE LOKALIZACJI

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Abstract

Regional economic activities and developments are measured through various techniques where Location Quotient (LQ) is one of the most reliable techniques. This paper classifies the settlements by economic potentials in the southern region of Niger state using the LQ. A structured questionnaire was administered to 1.040 in the 37 rural communities selected from 37 districts in 8 LGAs in the Niger South Federal constituency in Niger State. The data collected was analysed using LQ. Findings of the study in terms of economic potentials of the region, reveals that communities are mainly engaged in basic economic activities; including the cultivation of food crops (rice, maize, beans, millet and yam); cultivation of cash crops (benisead, ground nut, vegetable, cassava and melon), plantation agriculture (palm, kola nut, cashew and sugar cane). Findings in terms of basic economy revealed that Egbako has the highest LQ with an average score of 0.06, and is closely followed by Takuma, Batako, Kusoyaba, Mukugi and Kalmo, with an average LQ score of 0.04 each, while in terms of non-basic economy, the findings indicates that both Egbako and Kuchita have the highest non-basic LQ with an average score of 0.07, which were closely followed by Katcha, Mukugi and Gayankpa settlements with non-basic economic LQ and average scores of 0.04 each. The study concludes that LQ is one of the best techniques in measuring economic potentials of regions. It also recommends LQ for regional economic assessments.

Streszczenie

Działalność gospodarcza w regionie oraz rozwój regionu są mierzone różnymi metodami, wśród których iloraz lokalizacji (LQ) jest jedną z najbardziej wiarygodnych technik. Niniejszy artykuł klasyfikuje osady według potencjału gospodarczego w południowym regionie stanu Niger przy użyciu wskaźnika specjalizacji regionalnej LQ. Ankietę zawierającą pytania zamknięte rozdano 1040 osobom w 37 społecznościach wiejskich wybranych z 37 stref ośmiu obszarów samorządowych w okręgu federalnym Niger South w stanie Niger. Zebrane dane zostały przeanalizowane przy użyciu techniki LQ. Wyniki badania w zakresie potencjału gospodarczego regionu pokazują, że społeczności są głównie zaangażowane w bazową działalność gospodarczą, w tym uprawę roślin spożywczych (ryż, kukurydza, fasola, proso i ignam); produkcję upraw rynkowych (benisead, orzeszki ziemne, warzywa, maniok i melony), rolnictwo plantacyjne (palma, orzech kola, nerkowiec i trzcina cukrowa). Najwyższą wartość LQ dla działalności podstawowej uzyskało Egbako ze średnim wynikiem 0,06, następnie Takuma, Batako, Kusoyaba, Mukugi i Kalmo, ze średnim wynikiem LQ 0,04. Pod względem gospodarki nie-bazowej zarówno Egbako, jak i Kuchita mają najwyższe LQ ze średnim wynikiem 0,07, a tuż za nimi plasują się osady Katcha, Mukugi i Gayankpa ze średnimi wynikami LQ 0,04. W badaniach stwierdzono, że LQ jest jedną z najlepszych technik pomiaru potencjału gospodarczego regionów. Technikę tę poleca się również do wykorzystania przy sporządzaniu ekonomicznych ocen regionalnych.

ACCESSIBILITY STUDY OF HISTORIC BUILDINGS AND CONTEMPORARY HERITAGE – ON THE EXAMPLE OF KIELCE'S PUBLIC UTILITY BUILDINGS

STUDIUM DOSTĘPNOŚCI OBIEKTÓW ZABYTKOWYCH ORAZ DZIEDZICTWA WSPÓŁCZESNOŚCI – NA PRZYKŁADZIE OBIEKTÓW UŻYTECZNOŚCI PUBLICZNEJ KIELC

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Structure and Environment vol. 15, No. 3/2023, p. 133 DOI: 10.30540/sae-2023-012

Abstract

Ensuring the accessibility of buildings and spaces is a common contemporary challenge, in particular for historic buildings and spaces as well as the heritage of contemporary culture. It involves all activities aimed at adapting facilities and space to the needs of people with various disabilities, including seniors. The problem of aging societies and increasing life expectancy forces extensive changes both in the approach to architectural and urban design as well as in the practice of making historic buildings accessible through architectural solutions. Particularly in existing public buildings, it becomes very important to pay attention to the specific needs and reduced psychophysical abilities of various groups of architecture recipients due to their age. For this reason, the article analyzes the accessibility of selected examples of historical objects (case studies) functioning in the structures of the modern city of Kielce – for several dozen years. In order to get acquainted with the functioning and architectural solutions of buildings, which are among the most frequented by the general public, in situ research was carried out, the multi-criteria method was used, enabling comparative analyzes and being an effective tool in making a precise assessment. The research was focused on the location of the city of Kielce, taking into account current reports and statistics indicating the largest increase in the number of people over 65 in the Świętokrzyskie Voivodeship. It was found that it is important to revise the approach and generally accepted functional and spatial solutions regarding the accessibility of this type of facilities.

Streszczenie

Zapewnienie dostępności budynków i przestrzeni jest powszechnym współczesnym wyzwaniem w szczególności dla obiektów i przestrzeni zabytkowych oraz dziedzictwa kultury współczesnej. Wiąże się ono z wszelkimi działaniami służącymi dostosowaniu obiektów i przestrzeni do potrzeb osób z różnorodnymi niepełnosprawnościami, w tym seniorów. Problem starzejących się społeczeństw i wydłużania się długości życia wymusza szerokie zmiany zarówno w podejściu do projektowania architektoniczno-urbanistycznego, jak i praktyki w zakresie udostępniania zabytkowych obiektów poprzez rozwiązania architektoniczne. Szczególnie w istniejących budynkach użyteczności publicznej bardzo ważne staje się zwrócenie uwagi na specyfikę potrzeb i obniżone, z uwagi na wiek, możliwości psychofizyczne różnych grup odbiorców architektury. Z tego względu w artykule dokonano analizy dostępności wybranych przykładów historycznych obiektów (case studies), funkcjonujących w strukturach współczesnego miasta Kielce – od kilkudziesięciu już lat. W celu zapoznania się z funkcjonowaniem oraz rozwiązaniami architektonicznymi budynków, należących do najczęściej uczęszczanych przez ogół ludzi, przeprowadzono badania in situ, wykorzystano metodę wielokryterialną, umożliwiającą przeprowadzenie analiz porównawczych i stanowiącą skuteczne narzędzie w dokonaniu precyzyjnej oceny. Badania skoncentrowano lokalizacyjnie na obszarze miasta Kielce, mając na uwadze aktualne raporty i statystyki wskazujące na największy przyrost liczby osób powyżej 65 lat w województwie świętokrzyskim. Stwierdzono, że istotna jest rewizja podejścia i ogólnie przyjętych rozwiązań funkcjonalno-przestrzennych w zakresie dostępności tego typu obiektów.

DYNAMIC ANALYSIS OF A STEEL-CONCRETE RAILWAY BRIDGES OF LANGER TYPE UNDER THE INFLUENCE OF A MOVING LOAD

ANALIZA DYNAMICZNA STALOWO-BETONOWEGO MOSTU KOLEJOWEGO TYPU LANGERA POD WPŁYWEM OBCIĄŻENIA RUCHOMEGO

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Abstract

The studying the dynamic response of steel-concrete railway bridges of Langer type is huge importance of ensuring the safety of such structures under high-speed train loads. Numerical simulations at the design stage require knowledge of the modal characteristics: natural frequencies, shapes and damping. In addition, in the dynamics of railway bridges subjected to high-speed trains, it is important to check the impact of dynamic effects on the ultimate and serviceability limit states. As part of the investigations displacements and accelerations of selected measurement points arising from driving the test rolling stock are analyzed. In the first stage, calculations of the eigenvalues and the corresponding eigenvectors were carried out in the Robot program for two variants of mass description (distributed and discrete). In the second stage, dynamic train passages for various vehicle speeds were examined in terms of displacements and accelerations of measurement points by using the authors' program MES3D.

Streszczenie

Badanie odpowiedzi dynamicznej stalowo-betonowych mostów kolejowych typu Langera ma ogromne znaczenie dla zapewnienia bezpieczeństwa takich obiektów pod obciążeniem pociągów dużych prędkości. Symulacje numeryczne na etapie projektowania wymagają znajomości charakterystyk modalnych: częstotliwości drgań własnych, form i tłumienia. Dodatkowo w dynamice mostów kolejowych poddanych działaniu pociągów szybkobieżnych istotne jest sprawdzenie wpływu efektów dynamicznych na stany graniczne nośności i użytkowalności. W ramach badań analizowano przemieszczenia i przyśpieszenia wybranych punktów pomiarowych powstałych od jazdy taborem próbnym. W pierwszym etapie przeprowadzono obliczenia wartości własnych i odpowiadających im wektorów własnych w programie Robot dla dwóch wariantów opisu masy (rozłożonej i dyskretnej). W drugim etapie zbadano przebiegi dynamiczne dla różnych prędkości pociągów pod kątem przemieszczeń i przyspieszeń punktów pomiarowych za pomocą autorskiego programu MES3D.

APPLICATION OF DEEP LEARNING TECHNIQUES IN IDENTIFICATION OF THE STRUCTURE OF SELECTED ROAD MATERIALS

ZASTOSOWANIE TECHNIKI GŁĘBOKIEGO UCZENIA DO IDENTYFIKACJI STRUKTURY WYBRANYCH MATERIAŁÓW DROGOWYCH

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Abstract

In research, there is a growing interest in using artificial intelligence to find solutions to difficult scientific problems. In this paper, a deep learning algorithm has been applied using images of samples of materials used for road surfaces. The photographs showed cross-sections of random samples taken with a CT scanner. Historical samples were used for the analysis, located in a database collecting information over many years. The deep learning analysis was performed using some elements of the VGG16 network architecture and implemented using the R language. The learning and training data were augmented and cross-validated. This resulted in the high level of 96.4% quality identification of the sample type and its selected structural features. The photographs in the identification set were correctly identified in terms of structure, mix type and grain size. The trained model identified samples in the domain of the dataset used for training in a very good way. As a result, in the future such a methodology may facilitate the identification of the type of mixture, its basic properties and defects.

Streszczenie

W badaniach naukowych obserwuje się coraz większe zainteresowanie wykorzystaniem sztucznej inteligencji do poszukiwania rozwiązań trudnych problemów naukowych. W niniejszym artykule został zastosowany algorytm głębokiego uczenia z użyciem obrazów próbek materiałów wykorzystywanych do budowy nawierzchni drogowych. Fotografie przedstawiały przekroje losowych próbek wykonane za pomocą tomografu komputerowego. Do analizy wykorzystano próbki historyczne, znajdujące się w bazie danych zbierającej informacje z wielu lat. Analizę głębokiego uczenia wykonano przy użyciu niektórych elementów architektury sieci VGG16 i zaimplementowano, stosując język R. Dane uczące oraz treningowe poddano augmentacji oraz walidacji krzyżowej. W rezultacie uzyskano wysoki poziom 96,4% jakości identyfikacji rodzaju próbki oraz jej wybranych cech strukturalnych. Fotografie w zbiorze identyfikacyjnym zostały poprawnie zidentyfikowane pod względem struktury, typu mieszanki oraz uziarnienia. Wytrenowany model w bardzo dobry sposób zidentyfikował próbki w obszarze dziedziny trenowanego zbioru danych. W rezultacie taka metodyka może w przyszłości ułatwić identyfikację rodzaju mieszanki, jej podstawowych właściwości oraz defektów.

ASSESSING THE FINANCIAL BENEFITS OF USING A SHOWER DRAIN HEAT RECOVERY SYSTEM – A CASE STUDY

OCENA KORZYŚCI FINANSOWYCH Z WYKORZYSTANIA INSTALACJI ODZYSKIWANIA CIEPŁA Z ODPŁYWU SPOD PRYSZNICA – STUDIUM PRZYPADKU

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Abstract

The production of hot water for bathing in Poland accounts for around 15% of the total energy consumption of a typical household. According to EU data, final energy consumption for lighting and appliances is similar to final energy consumption for hot water preparation. This makes it a significant contributor to housing and utility costs, exceeded only by heating expenses. Research has indicated that only about 10% of the water utilized during a shower is necessary for hygiene purposes. Consequently, around 90% of the hot water supplied to the shower is ultimately discharged into the sewage system. By harnessing the primary energy from wastewater, we can effectively conserve heat energy and reduce the overall expenditure associated with hot water. The objective of this article is to explore the utilization of heat recovery from domestic wastewater as a means to enhance the energy efficiency of residential buildings.

Streszczenie

Wytwarzanie ciepłej wody w Polsce do kąpieli stanowi około 15% całkowitego zużycia energii w typowym gospodarstwie domowym. Według danych UE, końcowe zużycie energii na oświetlenie i urządzenia jest zbliżone do końcowego zużycia energii na przygotowanie ciepłej wody użytkowej. To sprawia, że jest to znaczący czynnik wpływający na koszty mieszkaniowe i użytkowe, przewyższany jedynie przez wydatki na ogrzewanie. Badania wykazały, że tylko około 10% wody zużywanej podczas kąpieli pod prysznicem jest niezbędna do celów higienicznych. W rezultacie około 90% ciepłej wody dostarczanej do prysznica jest ostatecznie odprowadzane do kanalizacji. Wykorzystując energię pierwotną ze ścieków, możemy skutecznie oszczędzać energię cieplną i zmniejszyć ogólne wydatki na ciepłą wodę. Celem tego artykułu jest zbadanie wykorzystania odzysku ciepła ze ścieków domowych jako sposobu na zwiększenie efektywności energetycznej budynków mieszkalnych.

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