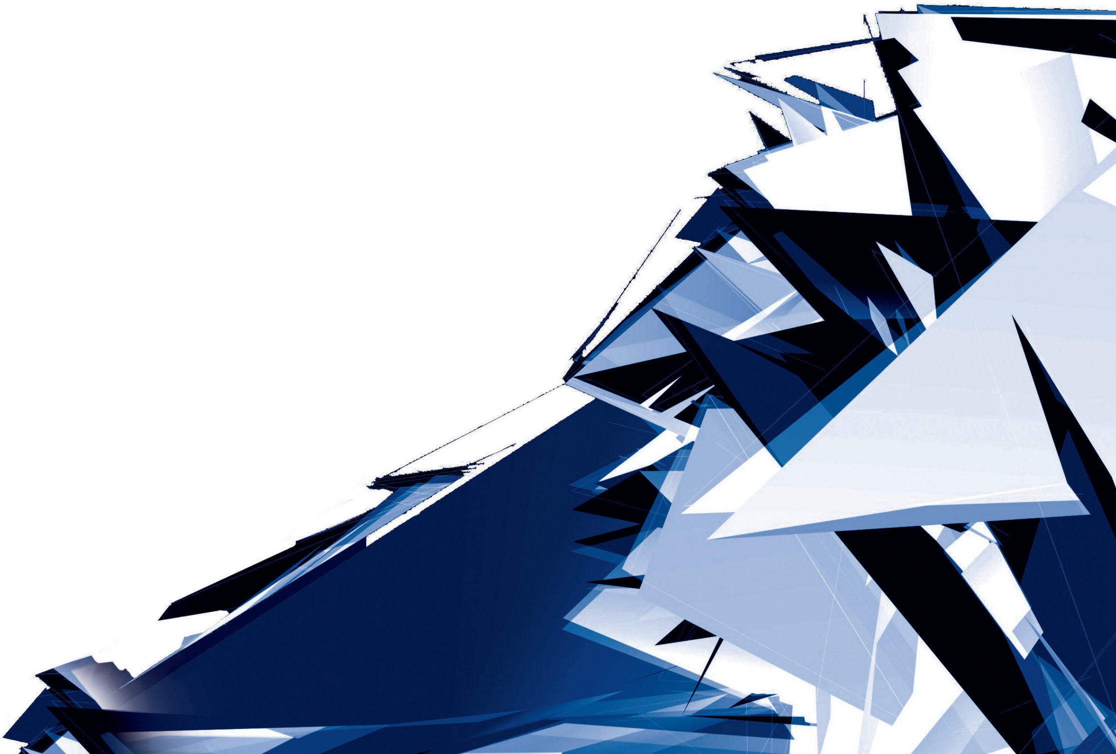
Technical Transactions

Czasopismo Techniczne

Volume 10

Year 2017 (114)



www.ejournals.eu/Czasopismo-Techniczne
www.technicaltransactions.com
www.czasopismotechniczne.pl

ISSN 0011-4561

Basic version of each Technical Transactions magazine is its online version
Pierwotną wersją każdego zeszytu Czasopisma Technicznego jest jego wersja online

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ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.17.165.7273

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Modern green technologies and solutions in landscape architecture

Zielone nowoczesne technologie i rozwiązania w architekturze krajobrazu

Abstract

The paper presents modern technological solutions used in landscape architecture, with special emphasis on their occurrence in the areas of historical greenery. Dynamic introduction of new tools allows us to take special care of valuable areas, stressing their importance and at the same time granting them new functions. The latter part discusses a specific example of this type of solutions from the area of Katowice. These are modern developments that make the historic pattern of industrial city more legible.

Keywords: modern technologies, landscape architecture, Katowice

Streszczenie

W artykule przestawione zostały rozwiązania nowoczesnych technologii stosowanych w architekturze krajobrazu ze szczególnym uwzględnieniem ich występowania na terenach zieleni historycznej. Dynamicznie wprowadzane nowe narzędzia pozwalają na objęcie szczególną dbałością te wartościowe obszary, podkreślając ich znaczenie równocześnie nadając nowe funkcje. W drugiej części omówiony zostanie szczególny przykład tego typu rozwiązań z terenu Katowic. Są to nowe realizacje uczytelniające historyczne układy miasta przemysłowego.

Słowa kluczowe: nowoczesne technologie, architektura krajobrazu, Katowice

1. New Technologies for areas of historic greenery

In a consideration attempt of the occurrence of new technologies in areas of historic structured greenery we have to define the space that we relate our research to. It is the vast collection of human-shaped terrains, differentiated in their functions, forms, history and traditions. In urban areas these include parks, squares, alleys, and roadside greenery planted till mid 20th century. The majority of these areas are protected, and works connected with them are mostly revalorizations, re-compositions and reconstructions. New tools are based on the development of new technologies that are linked to developments in different fields of science. These include: IT-development, access to the newest inventions and their synergy.

The changes occurring in technologies used in historic structured greenery can be divided in two groups. One of that serving the design process and the others applied in execution. New technologies used in design are of significant importance in conceptual considerations. They can substantially enrich the specialist research, broadening our knowledge of past of these locations. Archeological research based on computer tomography allow us to reveal e.g. relics of engineering structures, without interference with terrain. Botanical and palynological analyses connected with gathering information about preserved pollen in places that were not subject to soil replacement bring us the required knowledge of species composition that once grew in this area [13, p. 373]. Dendrological research allows for non-invasive determination of the condition of trees, measured with use of laser or ultrasound devices [1]. To this end portable devices are used, based on wireless communication. The biological surface monitoring is applied in case of vast spaces. A technology that links knowledge and concepts in a selected area that proves perfect for design are the Geographical Information Systems (GIS). These are integrated sets of an interface in form of a map, with spatial data databases. Numerical terrain models, 3D visualizations form a summary of application of computer technologies.

During execution stage methods based on innovativeness, ecology, and material engineering are implemented with use of advanced technologies [10, p. 146]. New solutions apply to use of water, light sources, different pavements and equipment elements.

Water has numerous values, other than just its aesthetic value, in historic greenery. When used appropriately it has important economic (protection of resources, health, condition of environment, microclimate of the city) and social roles. The systems for recycling of precipitation waters that are ever more frequently used allow to use them in an economical fashion. Watering networks grow in popularity, controlled with devices that are synchronized by measurements of soil condition and weather forecasts. Another function can be obtained by using water as a screen. This may be a temporary attraction in historic areas, during movie screenings or artistic events. We have sprinkling and gravitational screens that are commercially available. Depending on the type we can achieve laser and video images of different size. Sprinkling solutions require some 2 thousand liters of water per minute, and that is why they are usually installed on existing water reservoirs [18].

Introduction of lighting in the historic green areas frequently becomes an element that not only improves safety levels, but also shapes this space anew. From the beginning of 19th century lighting became applied on a larger scale in public spaces, including parks and greeneries [11]. Illumination with use of gas, and later also electric lamps was used. The latter one was a technological revolution that allowed application of those solutions on larger scale. The current breakthrough in lighting are the lighting management systems that allow the use of rational control systems that adjust the light intensity depending on the time and traffic in public spaces and arteries. Solutions based on solar technologies with small wind turbines added are used in parks and squares. Mapping is another tool used in historic complexes. It is used for "light and sound" shows. It enables the visualization of artistic narratives, that can make historic gardens more attractive [8, p. 256]. The presented contents are diverse, and based on history of location, legendary characters, shows of space creators. Such solutions enrich the terrain with new meanings, contents, improving their aesthetics.

Pavements are a separate group of modern technologies in developments, and this can be divided onto several types: pro-ecological, ecological and safe [17]. These are used for construction of roads for vehicles and for pedestrians. Pro-ecological can be recycled and used again once their lifespan ends. Permeable path surfaces made of mineral breakstone are environmentally neutral and both visually and ecologically valuable. It is also worth to mentioned the pavement materials made of granulated recycled materials. They are abrasion resistant.

Equipment elements that are modern both in their form and materials used are utilized in historic greenery complexes. This group becomes growingly legible for its recipients, sometimes utilizing light, texture, shape and composition that become the signature of the respective location. The seats that connect greenery in form of parklets, pergolas in different forms, visual information systems that aid terrain orientation.

The concept of Smart cities is based on integrated watering, traffic management, parking, environmental monitoring, cleaning, and lighting systems and Wi-Fi zones. Numerous facilities for communities, not just the local ones, are based on technological innovations. This is integration and monitoring of public services and the visible participation of dwellers in managing the city. This type of solutions is ever more willingly introduced.

The aforesaid modern materials find their application in many cities that strive to improve the quality of life by connecting new technologies with tradition of place. The example of such an implication are the areas of Katowice, described in detail below.

2. Modern solutions in the landscape of midtown Katowice

2.1. Location and development conditions of the analyzed area

The history of Katowice as a town dates back to beginning of the 2nd half of 19th century. The oldest buildings were constructed in 1860s and 1870s. Together with the historic development of an area a transformation of the architectonic tissue occurred, from single- and two-storey houses and villas, to several storey high townhouses and palaces of the turn of 19th and 20th century [9, p. 18]. In the interwar period Katowice became the third centre of modern architectural thought in Poland (only after Warsaw and Gdynia). This period saw the construction of vast public buildings and residences [12, p. 79].

Scope of these considerations includes the area of the market and the nearby Katowice Culture Zone, located in the area of the former "Katowice" Coal Mine. The mine, once situated northwest of the market, operated till 1999. In the last years the area witnessed numerous construction works, as a part of revitalization program or a larger reconstruction program.

It is worth stressing that the discussed examples should not be directly qualified to group of historic structured greenery, due to the scarce number of plants that appeared in its historic development. Lack of greenery was the result of their functions such as communication node, market square and mine. These locations are still examples of important public spaces with representative (market) functions and preserved historic values. The conditions for development of both areas are mainly connected with the Silesian traditions, including the industrial origin of the place These formed an important spatial context and a point of reference in the design concepts. Proximity of 20th century buildings, including objects with iconic status that became landmarks of that area also proved significant.

The Katowice market square was the first area to be analyzed and the oldest square in the city. It was the center of the former cottager's village of Katowice established in second half of 16th century. In this place main communication routes also crossed, with residential buildings located along them. In the second half of 19th century, as part of larger development plan for roads and buildings by German engineer – Heinrich A.M. Nottebohm the square was paved with cobblestone, surrounded with buildings and included in the urban composition of midtown Katowice [2, pp. 206–207]. This time witnessed numerous objects with large cultural value constructed on the sides of the square, bearing the idea artistic tendencies of the turn of 19th and 20th century. An example thereof is the building of the Silesian Theatre in the so called "near 1800 style", resembling the classicizing baroque [4, p. 192]. In its historic development the Katowice market square was frequently subject to considerations of architects and urban designers. Planning first changes occurred prior to 1939 and in the postwar period numerous plans for redevelopment were formed [2, p. 209]. Whole cultural heritage of the modernism age still plays an important role in city landscape, and similarly to the industrial objects influences the identity of the place.

The region of the today's Katowice Culture Zone is also of historic value. Due to its initial function as a mine area it is linked with *genius loci* (tradition of space). The Katowice Coal Mine (formerly Ferdinand) was one of the oldest industrial works in the city [3, p. 146]. The preserved mine buildings dating back to 19th and 20th century form an important part of the landscape, connected with history of this region and also one of the main design conditions. The other was the direct vicinity of iconic objects, including the Spodek Sport and Show Arena.

2.2. Redevelopment of Katowice Market Square

The redevelopment of Katowice market square started in 2012 and proceeded in stages. The Flower Square, located in southern part, was one of its important elements. In the initial stage of works the tramway rails that existed there, and the tarmac pavement were removed, the square was paved with granite. According to a design by the Redan design house of Szczecin a new spatial composition was introduce, based on regular system of trees and flower beds, surrounded by sitting places. Between them a marble fountain was constructed [16] (Fig. 1a). The greenery also appeared in the northern part of the market, where individual trees were planted, grass planted and pavements made of colorful tarmac introduced, due to the playground located in this part (Fig. 1b). Green walls located at the tramway rails (Fig. 1c) dorm an example of modern greenery forms in the market landscape. These act as an isolation, dividing the market square area and the noise and dust generated by vehicles, and also as a decoration – in form of intriguing composition of vertical gardens. They are first investment of this kind that was constructed in a public space on such a large scale [22].

Within the project, apart from pavement solutions and plants also water elements were introduced. Apart from the aforesaid miniature fountain in the Flower Square longitudinal water reservoirs were placed in the former trace of Rawa river, which today flows underneath the square surface (Fig. 1d). Wood-clad seats are located near the fountain and exotic plant species, brought in from the Gliwice town greenhouse, are placed there in the Summer. This composition is a direct reference to tradition of place, both by tracing the river, but also by continuing the tradition of collecting and displaying exotic plant specimens, that in Silesia dates back to the end of 19^{th} century. Throughout the summer period the surrounding of the artificial Rawa river enjoyed large interest both of local residents and tourists.

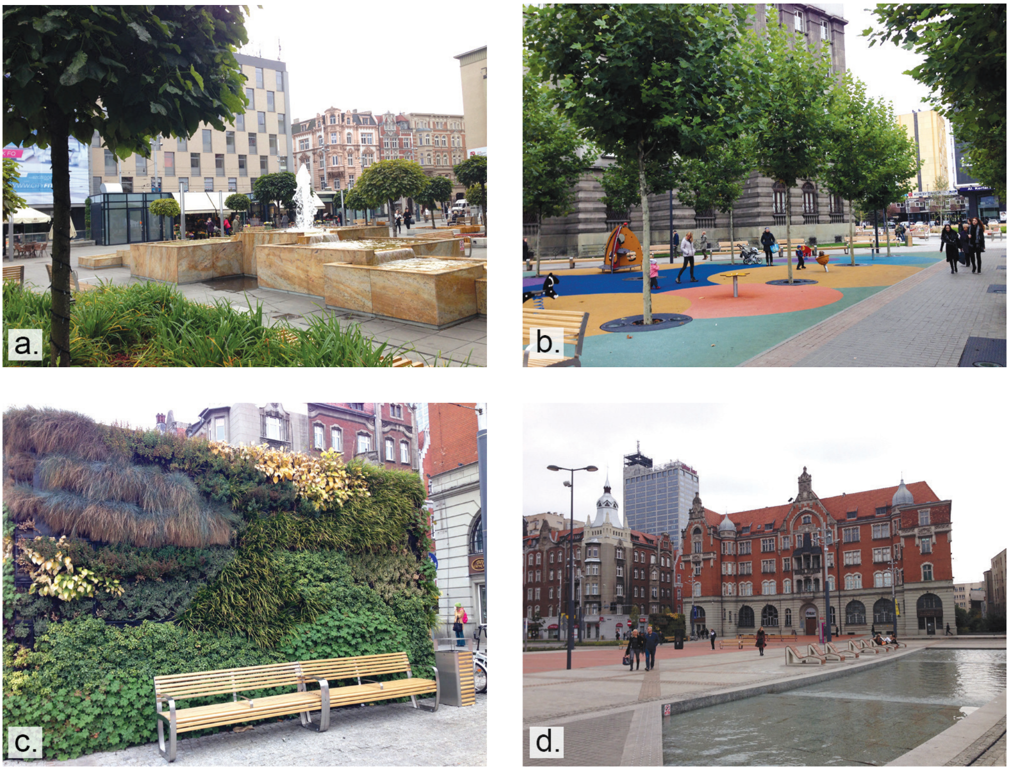

Fig. 1. a) marble fountain at the Flower Square, b) playground for children, c) fragment of the green wall (vertical garden), d) water fountain tracing the Rawa river (photo by E. Waryś, 2016)

The modernization of architectural objects also contributed to the changes of the landscape of midtown Katowice. The contemporary transformation of existing buildings is one of the factors influencing the perception of urban interiors. The example of a late-modernist object on the side of the market, that was recently modernized is the former Silesian Press Hous, currently housing the City Council. Within the redevelopment the introduction of a completely new structure was envisaged. In the market square this included, among others, a glazed pavilion in modern form, located in the northern part.

2.3. Katowice Culture Zone

Modern approach to shaping greenery areas, with use of new materials and technologies and the concurrent recalling to the tradition of place is also visible in the Katowice Culture Zone that is located on the grounds of the former Katowice coal mine. This place, located to the east and southeast of the Katowice Spodek arena houses three objects integrated with greenery areas. Designs for all three buildings were selected in international architectonic design competitions. Today they form the most modern exhibition and conference complex in the region, directly neighboring with existing developments, including the solid of the Spodek arena, which due to its unique form had to be kept sufficiently exposed [15, p. 38].

The object located closest to the Spodek hall is the building of the International Congress Center, designed by JEMS Architekci studio and opened in March, 2015. This object is one of the most modern examples of connection of architecture and greenery and a novel recalling of the Silesian traditions. What is of symbolic dimension is, e.g. the black color of the façade, inspired by the coal mine that once existed in this place. This contrasts with the greens of the deformed roof, where a walking path was located, with seats, lighting and vista terraces [15, p. 38]. The intention of the architects was to construct a building on a landscape scale, divided by a garden canyon, linking the square at the Spodek arena with a historic path towards Bogucice district [19]. Introduction of walking paths, stairs made of black concrete, allowed the visitors to see the building and its vicinity from a new, changing perspective [14, p. 49]. Even if the solid of the building is to some degree reserved it utilizes many atypical construction systems, consisting of irregular shapes, girders and systems of ribs, that form the base of roof slab [7, p. 58]. Currently the object stands out in the city landscape, and at the same time forms background for preexisting buildings.

To the northeast of the congress centre the building of the National Symphonic Orchestra of the Polish Radio [NOSPR] is located, designed by the Kanior Studio of Katowice. In this case, along the brick solid of the building, which was moved to the southern border of its site on purpose, a public space with a traditional city scale was designed that is characterized by large amount of greenery. In front of the frontal façade a fountain was located that reflects the glyphs of window openings (Fig. 2.a). There is a concrete footbridge nearby, that leads towards the Spodek arena. To the northeast an amphitheatre was located, and isolated, wood-covered banks. To the north of the building a park was located with irregular plants grouped along the borders of the site. Both the object and also the space surrounding it are full of symbolic meanings and references to traditions of the region. The hornbeam labyrinth, located in the northeastern part, is an example – with its shape reflecting the urban fabric of the prewar design of midtown Katowice (Fig. 2.b). Also the building façade recalls the colors of Silesian worker's districts such as the Nikiszowiec of Katowice and the functional-spatial design is the reflection of design assumptions that are characteristic for modernist architecture [6, p. 46].

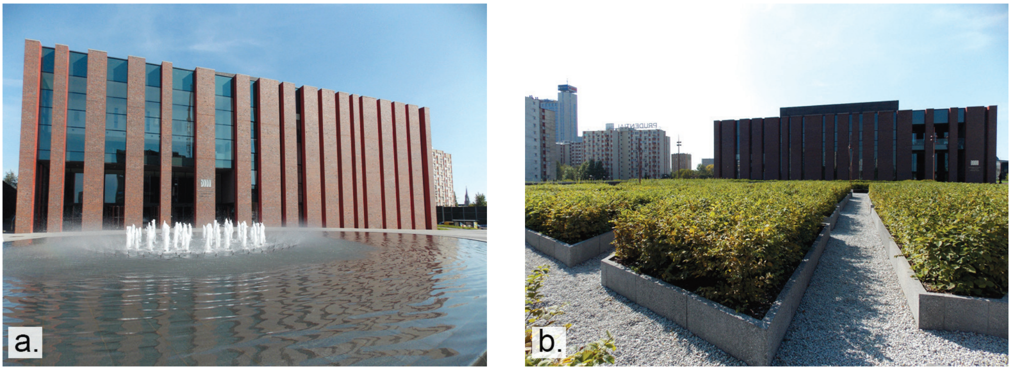

Fig. 2. a) fountain at the front façade of NOSPR, b) hornbeam labyrinth (photo by E. Waryś, 2015)

On the eastern side of the NOSPR the new seat of the Silesian Museum is located, designed by the Austrian Riegler Riewe Architekten studio of Graz. Pursuant to project assumptions the majority of exhibition spaces was located underground. There were glass boxes lighting the interiors and a surrounding park located at the surface. The new gardens were divided by a geometrical system of pathways, supplemented by decorative flower beds. The glass cubes visible on the surface follow the pastel colors of the gardens. Apart from the above the museum grounds also include preserved former mining objects, adopted to their modern functions. An example of that is the winding tower of the mining shaft, now turned in a vista point [21].

The developments located in the Katowice Culture Zone on numerous occasions met with both enthusiasm of local residents and architectural experts, and also with critic. The lack of a master plan for the whole area that would be based on reliable studies and pre-design analyses met with negative reactions. Even with zoning regulations in place for that area their assumptions were not included and the areas surrounding the respective buildings were designed by different designers. Another problems is also the competitive character of that area, as a result of gathering many cultural objects in one place [15, p. 39]. Another questions arose around the development of Katowice market square. An example of critic of the developments of the city was an artistic installation at the outflow of Rawa river, near the market square, with a neon-light reading "sundown". This installation was part of the Katowice Street Art Festival and its intention was to point viewers attention to the superficiality of the developments in Katowice and their sort of incredibility and artificiality [20]. Negative comments of this type, appearing with new investments, revealed the problems that were not solved to date, and the conflict areas that occurred in the public space. On the other hand the success of the completed investments is proved by constant interest demonstrated by residents and tourists and the large number of architectural prizes that the respective objects won.

3. Summary

Modernity of the investments discussed is demonstrated in materials, construction systems and functional solutions applied therein. The compositions that were introduced frequently departed from standard design schemes and opened towards the non-standard solutions. What is worth stressing from the viewpoint of rules for landscape design are the efforts to develop the space in the most effective manner and introduce diverse forms of designed greenery. Even using modern forms the designers of all projects aimed at preserving the identity of place and reached for inspirations from local traditions. The example of the discussed investments shows that introduction of designed greenery in design program allows for aestheticization and enhancement of attractiveness of city landscape.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

ARCHITECTURE AND URBAN PLANNING

DOI: 10.4467/2353737XCT.17.166.7274

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Contemporary art in the historic landscape

Sztuka współczesna w krajobrazie zabytkowym

Abstract

The paper discusses the subject of the introduction of modern forms into spaces of a historical character, mainly into historical gardens. Its aim is to present the general tendencies, causes and scope of the introduction of modern art into these types of interiors, the problem of their interference with historical tissue, its scope and goal, along with an outline of general guidelines for these types of projects.

Keywords: historical gardens, art, contemporary art, monument preservation, exhibition design.

Streszczenie

Artykuł porusza problematykę wprowadzania nowoczesnych form do przestrzeni o charakterze historycznym, głównie do ogrodów zabytkowych. Ma ca celu przedstawienie ogólnych tendencji, przyczyn i zakresu występowania współczesnej sztuki w tego typu wnętrzach, problemu ich ingerencji w tkankę zabytkową, jej zakresu i celu, wraz nakreśleniem ogólnych wytycznych do tego typu działań.

Słowa kluczowe: ogrody historyczne, sztuka, sztuka współczesna, konserwacja zabytków, projektowanie wystaw

1. Introduction

Widely accepted and currently held definitions describe the cultural landscape as a recording of human deeds and history, containing natural and civilisational elements [1]. Every landscape produces emotion and possesses tangible and intangible values. Historical urban landscapes are particularly saturated with them, being urban spaces that constitute the effect of the layering of cultural and natural values, as well as containing a series of attributes that are discussed in the wider context of a site [10, p. 5]. This context includes compositional and aesthetic categories – the analysis of space as a work of art created by generations of architects, urban planners and artists, exhibiting not only the aesthetic currents of a particular period, but also a combination of other factors – including cultural, social and economic ones. The evaluation of a historical landscape constitutes a difficult and still widely disputed problem, in particular as elements that determine its value or that have value in and of themselves, are numerous, overlapping and layered [9].

Art, the art of garden design and the art of the landscape are subjects which have been intertwined since the dawn of history. The landscape, the garden, landscape and garden interiors can constitute a work of art, house other works of art and can be an inspiration for the visual arts (Fig. 1, 2), finally, they can become a scenography, a background for the presentation of these works. The fine arts can round out a work of landscape architecture and garden design, they can create new effects and values. Finally, works of art can be made in order to transform an existing convention and form of a park or a garden (flower and garden exhibition, as well as land art are a separate issue).

Fig. 1. Mirabell Palce and Garden, Salzburg, classic pergola (photo by K. Łakomy, 2017)

Fig. 2. Garden at Arsenale, Venice Biennale of Architecture 2014, pergola as a work of art (photo by Ł. Sarnat, 2014)

2. Goal and scope of research

This article discusses the subject of the scope of the interference of a modern artist into historical tissue, especially that of gardens. It features a discussion on the history of such activities: modern tendencies in the visual arts that appear in historical landscapes. On the basis of an analysis of a selection of gardens and historical parks, in which modern forms have been added, the positive and negative consequences of such actions will be pointed out. The conclusion will be formulated in the form of guidelines that can be used in modern revalorisation work on gardens and those referring to the scope of the introduction of modern objects, elements and materials into the space of areas featuring historical greenery.

According to the "Florence Charter" a historical garden – "is an architectural and horticultural composition of interest to the public, deemed a historical monument, composed of living material and includes the arrangement of an area and its terrain, plant complexes, structural and decorative elements, as well as water" [3]. However, according to Professor Mitkowska, "it is a work formed from plant substance, integrally combined with architectural elements and shapes (...). It is a cultural treasure, of historical, scientific and artistic value" [5, p. 19–20].

The defining and determining of the scope of modern art that is being created by artistic movements, tendencies and manifestos, as well as technology and new media, is much more difficult. Today, the form of artistic expression has an immense amount of potential (media), but its goals remain the same: ethical, aesthetic, communicational, cognitive or ludic. Apart from architecture and design, sculpture, performance art, installations and all manners of new media art forms (as well as multimedia) appear in an interaction with the landscape and the garden.

3. Introducing new forms into historical spaces

Works of the fine arts have appeared within garden spaces since ancient times, usually in the form of frescoes decorating the architecture accompanying gardens and sculpture in the form of reliefs, freestanding works and those composed into water layouts. They started to be used particularly often after the Renaissance period [7, p. 227]. Various vases, sculptures, statues, sarcophagi are elements of the furnishing of squares and gardens that round out the basis of composition and the content layer of a garden (through the use of symbolism, allegories or apotheosis). They could take on the form of trophy collections, authentic mementos of travels or forms that bring memories of said travels to mind (Hadrian's villa in Tivoli) or the fragments of buildings, details, inscriptions, headstones (*lapidarium*). They could play an educational or political (e.g. Stowe) role, constituting a part of a garden's "narration", stimulating contemplation (ancient motifs) or create various types of atmosphere (ruins, temples, stones).

They were laid out either individually or in the form of alleys (e.g. Herenhausen), and special spaces within a garden were planned for their exhibition (e.g. Benrath, Fig. 3). They were often provided with a special framing in the form of plant compositions, loggias, recesses or plinths. The objects that were presented originated from earlier periods (mainly from ancient Greece and Rome), however, they were most often from the period in which a garden and its accompanying structure (chiefly palaces and villas) were built, being the result of the inventiveness of designers, deeper ideas or the ambitions of their owners (Sacro Bosco in Bomarzo, Fig. 4) or their passion for collecting (e.g. villa Borghese in Rome).

The tradition of organising sculptural exhibitions in public gardens (e.g. the Royal Baths) dates back to the XVIII century. Sculpture parks, which constitute a variation of a public park, built as a permanent exhibition of a collection of works by a single artist (e.g. the Park of Gustav Vigeland in Oslo) or of numerous artists (Chianti Sculpture Park) are a separate subject (because the idea of their origin and composition is the art exposition) .

Fig. 3. Benrath Palace and garden, Germany, Terrace with statues (photo by K. Łakomy, 2005)

Fig. 4. Sacred Wood of Bomarzo, Italy, Statue of Winged Fury and lions (photo by K. Łakomy, 2017)

In the case of infills within historical greenery performed through the actions of modern artists, their reception can be varied, and decisions regarding their placement within a historical context are widely discussed. Apart from an often obvious desire to stimulate emotions or to play with conventions, symbolism or form, which forces the search for deeper connections between a new element and the historical site, it would be appropriate to point out the aspect of the attractiveness of a space for exhibition purposes. Both historical gardens and parks, as well as historical urban interiors are characterised by order, harmony, often a compactness and uniformity of their composition, as well as by their materials. This is why they constitute and excellent field for exhibition – both due to the uniformity of the background, as well as due to the contrast between the old and the new.

4. Modern art in historical gardens – examples

The adaptation of historical green spaces to the needs of modern users is the basic subject that is discussed in the making of decisions regarding the scope of conservation. According to the Venice Charter (as well as the Florence Charter), every infill within a historical structure should "bear a sign of our times". In the case of introducing massings into historical gardens, they are usually given a modern form, while in the case of fittings and street furniture, the general tendency leans towards the introduction of forms that are similar to historical ones (the Pilinitz gardens), often using modern materials (concrete, steel), with completely new solutions (e.g. Leonberg, Pomeranzengarten – seats and pergola) being rarer.

Bobola's gardens in Florence constitute one of the more beautiful gardens of the Italian Renaissance and are included on the UNESCO World Heritage Site List. Their history extends to the XV century, and their prime is associated with the Medici family, mainly with Cosimo I and his son Francis I. The author of the initial plan was Niccolò Tribolo, however, after his death (in 1550), finishing the construction was successively supervised by other artists, including: Giorgio Vasari, Bartolomeo Ammannati and Bernardo Buontalenti. The garden was successively embellished and redesigned during subsequent periods. Its distinctness is evidenced by an outstanding spatial composition which makes use of the shape of the terrain, that combines geometric and free layouts of greenery with groups of sculptures in a particularly successful manner. They are not only classical forms, but also rustic and ancient ones, the figures of heroes and gods, as well as those of animals (dogs), in addition to the placement of an authentic Egyptian obelisk. In 2008, the "Tindaro Screpolato", a sculpture by Igor Mitoraj, was introduced into this layout (Fig. 5). The monumental form of a classical, cracked face was placed near a neatly cut row near Prato dei Castagni, providing the space with additional value, eliciting a lot of emotion among visitors.

The layout of the Irish Kilmainham Hospital and Garden in Dublin, which constitutes a part of the cultural heritage of Ireland (Ireland Heritage), currently houses the Irish Museum of Modern Art. The history of this structure goes back to the year 1684, when a hospital for war veterans was opened here- founded by James Butler (the Duke of Ormond and Vicery, followed by Charles II) – modelled after the Les Invalides in Paris. The revalorisation of the whole complex began in the 1980's. The current form of the former herbal garden was based on archival plans and constitutes an example of a geometric, representative formal garden. It also houses classical sculptures, mostly female figures and vases, however, due to its new function, modern art has been introduced here as well. In the courtyard, near the main entrance, "The Drummer", a sculpture by Barry Flanagan, has been placed, while on the crossing of the main axes of the composition, the "North South East West" fountain by Lynda Benglis, has been located (Fig. 6). Temporary exhibits also appear in the garden, such as the „Kilkenny Limestone Circle" by Richard Long or "217.5° Arc x 12" by Bernar Venet. On the other hand, the terrace between the courtyard and the main garden constitutes a typical exhibition space, although with a decidedly more modest character and a limited amount of greenery.

Fig. 5. Boboli Garden, Florence, "Tindaro Screpolato" (photo by K. Hodor, 2009)

Fig. 6. Kilmainham Hospital and Garden, Dublin, the fountain "North South East West" (photo by K. Łakomy, 2012)

The Chatsworth Garden in England is also a historical garden of unique value, in the interiors of which modern works of art are being presented. In this case, it was an exhibition titled "Beyond Limits – Sotheby's at Chatsworth: A Selling Exhibition", which took place in 2012 as a temporary exhibition presenting sculptures meant for auction by the Sotheby's international auction house. The palace and garden layout under discussion is dated to the year 1555. The first garden in the Elizabeth style was designed by William Cavendish, while it owes its current form to Lancelot Capabilit Brown and Joseph Paxton. Despite this, remaining in the hands of a single family, it has preserved its uniform, formal character and, contrary to the two earlier examples, is subjected to frequent and constant care.

The vast green interiors, the shape of the terrain around the palace, as well as numerous water artefacts make the exhibition of the works that are presented here exceptionally spectacular. This effect is additionally heightened by contrast. During the aforementioned exhibition, against the backdrop of this historical garden, works such as Tony Cragg's "Declination", Zaha Hadid's "Lilas in Bloom" or "Hoop-La" by Alice Aycock were presented.

Fig. 7. Chatsworth Garden, "Lilas in Bloom" Zaha Hadid, [11]

Fig. 8. San Quirico d'Orcia, Itay, Temporary exhibition in *Horti Leonini* (photo by K. Łakomy, 2014)

5. Guidelines for areas of historical greenery

Every green historical area represents a set of individual qualities. Adapting these types of areas to new forms of use is always connected with transforming their spatial structure, which, from the point of view of conservation, can constitute a threat [2, p. 160], but also an opportunity to elevate their attractiveness and popularity (ill. 8). Regardless, it is important that during such activity, the following elements are taken into account:

- the value of a space, the landscape and the value and class of a structure,
- the uniqueness of a space, the landscape and the uniqueness of a structure,
- the scale of a space and the scale of the structure,
- harmony and uniformity or contrast and diversity,
- the invasiveness of an object of art to the space of a garden,
- the influence on a change in intensity or form of use due to visitors coming to a garden.

A space of historical greenery can also be a place of organising temporary presentations, both of pure art, as well as from the field of exhibition, for instance in the form of open air thematic exhibitions. In such situations, the designer of such a project should consider the problem through multiple layers. It seems, the basic aspects are:

- safety (of a park, a visitor, a structure),
- functionality
- circulation within a park,
- circulation within an exhibition project, including one that provides a continuity of narration and a clarity of script,
- relation with extant space,
- technological non-invasiveness,
- the factual accuracy of a project,
- formal cohesiveness or contrast (form, material and technology, colour, etc.),
- scale in relation to the park and its elements (plants, fixed furnishings, infrastructure, etc.).

6. Conclusions

In light of the analyses that have been performed, it seems that the subject of the introduction of new elements into historical gardens and parks, both of a functional character – such as benches, lighting, litter bins, etc. as well as of an aesthetic one – chiefly works of sculpture, in addition to educational ones – temporary exhibitions, is still quite controversial. However, there is a lack of clear guidelines regarding the form, material, scale and the manner of the placement of such objects within a space. In practice, conservation designs are based on the knowledge, experience and aesthetic taste of their authors. They should always be preceded by studying the structures and by comparative analyses, keeping in mind that new elements cannot interfere too strongly with the extant layout, leading to its significant transformation. Acting in accordance with the principle of Professor Janusz Bogdanowski, that we should always act as to benefit a historical site, modern furnishings, works of art, as well as other activities should enrich historical parks and gardens with new values, content and emotions, while at the same time preserving their historical character.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017
ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.17.167.7275

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Contemporary spatial composition of historic architectural-garden systems and urban parks in the area of Warsaw Escarpment in the district Mokotów in Warsaw

Współczesna kompozycja przestrzenna historycznych układów architektoniczno-ogrodowych i parków miejskich w rejonie Skarpy Warszawskiej na obszarze dzielnicy Mokotów w Warszawie

Abstract

The article presents the contemporary spatial transformations of valuable architectural-garden systems and urban parks shaped in the area of Warsaw Escarpment in the district Mokotów in Warsaw: residential complex Królikarnia and Park Arkadia, residential complex Mokotów and Dreszer Park. Contemporary spatial composition of the complexes refers to carefully composed landscape of original projects, which emphasized the most valuable characteristics of the place, but also indicate many spatial transformations of study areas as well as the areas located in the immediate vicinity. These transformations are both positive and negative. Among the positive changes it is necessary to mention contemporary attempts of shaping and use of public spaces in parks and complexes, together with the processes of revalorization of different elements.

Keywords: composition, urban park, public space, Warsaw Escarpment

Streszczenie

Artykuł przedstawia współczesne przekształcenia przestrzenne najcenniejszych układów architektoniczno-ogrodowych i parków miejskich ukształtowanych w rejonie Skarpy Warszawskiej na obszarze dzielnicy Mokotów w Warszawie: zespołu rezydencjonalnego Królikarnia i Parku Arkadia, zespołu rezydencjonalnego Mokotowa oraz Parku Dreszera. Współczesna kompozycja zespołów nawiązuje do starannie komponowanego krajobrazu pierwotnych założeń, który podkreślał i wydobywał najcenniejsze cechy miejsca, ale także ukazuje liczne przekształcenia przestrzenne badanych obszarów, jak i terenów położonych w najbliższym sąsiedztwie. Przekształcenia te mają charakter zarówno pozytywny, jak i negatywny. Wśród pozytywnych przemian można wymienić współczesne próby kształtowania i użytkowania przestrzeni publicznych zespołów wraz z procesami rewaloryzacji różnych elementów.

Słowa kluczowe: kompozycja, park miejski, przestrzeń publiczna, Skarpa Warszawska

1. Introduction

Vistula River in Warsaw with its valley, terraces and high escarpment on the left bank was a major factor of the city location, and for centuries it has determined its spatial development and cultural landscape, shaping its identity. The high escarpment as the single eminence on the flat Mazovian plain and the main landscape value of the city, caused the creation of the most magnificent architectural and urban complexes on its area. The composition of these complexes consciously emphasized the most valuable features of the natural landscape of the place. Most of the historical complexes were planned on axles perpendicular to the edge of the escarpment. All urban complexes and even single buildings had view points or wide view openings towards Vistula Valley and forests on the other side of the river, and were carefully composed, what created a very harmonious landscape of escarpment and panorama of the city, visible from Vistula River [7, p. 195–216].

First on the edge of the escarpment there was located the Duke's seat, then Old Town with Royal Castle, New Town, then other royal, magnate and noble residences (manor-houses, palaces and villas with terrace gardens), temples and monastic architectural and garden complexes. Until the nineteenth century buildings on the area of the escarpment had a rather homogeneous character. Along the whole of today's urban section of the escarpment, a series of complexes were developed (urban or rural residences). The most important architectural objects and architectural and urban complexes shaped until the 19th on the area of the escarpment are: Old Town with Royal Castle, New Town, Kazanowscy and Koniecpolscy residences, Kazimierz' Villa Regia (17th century), rural residences: Ujazdowski Castle with gardens – Ujazdów (17th century), Marymont (Sobieska), Młociny (Brühl); in the second half of the 18th century: Ustroń, Książęce and Góra, Mokotów, Królikarnia, Roskosz, Natolin; in turn of the 18th and 19th centuries: the residential district of Żoliborz [10, p. 49–60].

In the eighteenth century, two large-scale spatial complexes related to the escarpment were planned: Saska axis (1720) and Stanisławowska axis, created in two stages (1 – Calvary Ujazdowska and Piaseczyński Canal) – in the second half of the 18th century, 2 – "Latawiec" road system in 1770, which contributed to the development of the southern district of Warsaw) [13, p. 83–98].

Among the next large-scale complexes connected with the escarpment and shaped on the basis of its unique landscape values it is necessary to mention: Wilanowski Key and complexes in the forest areas of the northern territory (Młociny, Bielany, Marymont) [3, p. 101].

Most of the residential complexes on the escarpment area were located in places of changes of the escarpment line, in contact with the edge ravines in order to enhance view values of the place.

"Parks located on the escarpment area have created their own specific layout. They consisted of an upper, usually regular garden, and a palace on the edge of the slope, which determined the main axis of the complex. The lower garden beneath the slope, had free composition. Both parts of the garden were linked by view axles" [11, p. 101].

Today the area of Warsaw Escarpment is still one of the most valuable cultural landscapes in the town. However, we can observe many spatial transformations of this area. The political, economic and social transformations in the last two decades have greatly influenced the development of the city, shaping and often restoring its cultural identity, also connected with the area of Warsaw Escarpment. There was an increase of the role of cultural landscapes in the city as well as there were changed the patterns of leisure time. Unfortunately, changes are also related to growing investment pressure on these areas. It is possible to observe, that the most precious values of the cultural landscape of Warsaw Escarpment have been lost in some of its sections, and the new plans and propositions of the development of the escarpment area have been taking them into account in varying degrees [7, p. 195–216].

Therefore the propositions of shaping the landscape of the escarpment are very important. They will become elements of a larger urban composition, so important in the process of planning the sustainable development of Warsaw.

Many experts recognize and perceive Escarpment's threats, but also think that we would be able to prevent them:

"We still have great opportunities and chances – to save and enhance an extraordinary meeting in the city space, which is the integration of diverse forms of living nature: wild and cultural forms; outstanding complexes of cultural heritage on the Escarpment and beneath it" [12, p. 24].

"Warsaw Escarpment requires protection as a magnificent work of nature and the man who shaped it, creating conscious spatial compositions. They were designed and created thanks to royal, magnate, church and bourgeois patronage. The escarpment has been for centuries the line of reference of Warsaw's urban complexes and plans that shaped its cultural identity. As an area of special historical and landscape value, it should be a constant concern for town planners, according to the tradition of good periods of planning of Warsaw's development. The areas beneath the slope, on its slope, and on the upper terrace – within the view reach – require great care as well as culture of investment and design" [13, p. 96].

2. The purpose of the research, the methodology

The main purposes of the research presented in the article are following: 1/detailed studies of contemporary spatial transformations of the most valuable architectural and garden systems and urban parks shaped in the area of Warsaw Escarpment in the area of Mokotów district in Warsaw, 2/general studies of contemporary spatial transformations of areas located in the immediate vicinity of architectural and garden systems and urban parks in the area of Warsaw Escarpment and Puławska street, 3/determining the influence of transformations on the spatial composition of the studied complexes and their identity and quality. The research has been carried out with taking into account the existing state of knowledge and with applying methods proper for the morphological research of urban space. There have been used the following research methods: 1) method of analysis and criticism of sources (planning documents, literature, design projects), 2) observation method (used for the evaluation of the existing conditions), 3) comparative method.

3. The description of the research and results

The main elements of the natural landscape of the Vistula Valley are the high escarpment on the left bank, flood terraces with old river beds, lakes, wetlands and marshy areas. The most important feature of this landscape is the continuity of all elements: river valley with vegetation and its edges. Despite this characteristic feature, the areas linked with Warsaw Escarpment within the present administrative boundaries of the city differ in both natural and cultural terms.

There are three important areas to be identified here: the northern one (where there survived forest areas near the city), the inner city area (within the trenches of the 18th century, characterized by the earliest and most intense urbanization, and the largest transformations of natural landscape), the southern area (where the development of agriculture on fertile soils was visible). The escarpment in the southern area has moved away from Vistula River, creating a framework for the vast valley. Within the areas mentioned above, many spatial or cultural landscapes can be identified [4, p. 124–137].

At present, the southern part of Warsaw Escarpment can be divided into four sections, characterized by different ways of development and degree of transformations: 1) section from Lublin Union Square to the South Station (subject of research in the area of Mokotów district), 2) section from the South Station to Służew complex, 3) section from Służew complex to Natolin Park, 4) section from Natolin Park to the administrative border of the city.

Warsaw Escarpment on the city area has a various course. On the section from Lublin Union Square to the South Station the escarpment moves away from the river at a distance about 5 km (large area of terraces). The relative height of the slope in Mokotów area in characteristic places is following: Mokotów – 14 m, Królikarnia – 20 m, Służew – 14 m, (height referring mainly to the adjacent Wilanowski terrace). The slopes angles of the escarpment in Mokotów area (from the Służewiec Valley to the Śródmieście district border) are various – both steep and mild sections are here (about 12–30° slope). Warsaw Escarpment in Mokotów area is a wet slope (numerous springs, dunes at the foot of a slope, wet meadows in the scarp zone).

The history of the Mokotów district (located on the left bank of the Vistula River, on the vast upper and lower areas of Warsaw Escarpment) dates back to the 11th century, when the first traces of settlement appeared (Mokotowo village). Thanks to the green scarp, numerous parks and greenery of streets and gardens, this district is considered to be extremely green today. Mokotów's remarkable location resulted in a considerable development in the 17th and 18th centuries, when wealthy burghers and aristocrats erected villas and palaces with gardens, designed by prominent architects: Tylman of Gameren, Dominik Merlini, Szymon B. Zug, Jakub Kubicki, Jan Chrystian Szuch, Efraim Schroeger [1, p. 5–88, 8, p. 114–122].

Mokotów and Królikarnia are the most important architectural and urban complexes shaped on Warsaw Escarpment area in the Mokotów district. At present, residential complexes of Mokotów and Królikarnia are also among the most important types of spatial architectural and garden systems existing in the escarpment area. These two spatial systems of gardens linked with the scarp are based on the connections with shaped water reservoirs (artificial ponds) beneath the slope due to the considerable distance of the river from the escarpment [6].

In the 19th century, Mokotów became a prestigious summer resort – there were built numerous health and recreational buildings, guest houses and inns. Mokotów's spatial development was limited at the end of the 19th century (1883) through the system of forts (Fort Mokotowski, Fort Odyńca, Fort Legionów), which formed the first ring of fortifications of the Fortress of Warsaw. At the turn of the 19th and 20th centuries, many new streets of today's Old Mokotów were proposed during the process of parceling of the former Mokotów Manor. The area of Mokotów with 28 thousand inhabitants, was attached to Warsaw in 1916, resulting in further development of the district (the construction of representative villas and townhouses incorporated into green areas, offices, scientific institutes, hospitals, schools, colleges, modernization of Puławska street, introduction of tram lines). The buildings were introduced into escarpment area in the Mokotów district in the interwar period (mainly housing). The district Mokotów was transformed in that period from a suburb of a cottage style into a modern residential and service center (more than 89 thousand inhabitants in 1939). The district is an area, which was often destroyed and then rebuilt: the first destruction occurred by the Swedish army in 1655–1657, than following the Kościuszko insurrection in 1794, and after the November Uprising in 1830. World War II brought huge losses of the population and destruction in the Mokotów district, especially during the Warsaw Uprising (in the defense of the district died soldiers of the Home Army regiments, scouts of Gray Battalions and civilians, 65% of buildings have been ruined). After the war, the Mokotów district was rebuilt and expanded, including residential and park complexes [1, p. 5–88, 8, p. 114–122].

It should be added, that Puławska street in the area of the Mokotów district is a part of the unique road in Warsaw townscape and one of the main road routes of the city. On the section from Lublin Union Square to the South Station, Puławska Street has special landscape features: it runs very close to the edge of the escarpment and its eastern frontage (continuous and compact) is continuous and compact interrupted rhythmically by green open areas. There are existing unique view openings from the street to the lower terraces, what allows inhabitants and tourists direct contact with the escarpment area. For these reasons, open areas that are part of this section should not be built.

The first opening from Puławska Street is Goworka street, and the second one (situated about 300 meters from the first one) is a wide belt of green – it is the beginning of the vast **Morskie Oko Park**, which from the east reaches Belwederska street and Łazienki Park, and from the south almost Dolna Street (founded in 1955, according to the design of E. Jankowska). The upper edge of the escarpment in the park is a magnificent viewpoint towards the lower terrace with Morskie Oko pond in the foreground, greenery (including green of the Łazienki Park) and housing on the lower terrace visible on the horizon. This panoramic view is much more diversified, because the first observation plan is closed by green scenes of varied species, what is giving the impression of extensive green interior. It should be emphasized that the view point is in the immediate vicinity of Puławska Street, what allows partial observation of views also by people on the street. Unfortunately, apart from the low development, there were designed also high housing buildings in the area on the edge of the escarpment, built above the average height of tenement houses forming the frontage of Puławska Street, together with pavilions occupied large surface on the ground floor. At the edge of the escarpment at the entrance to the park there was also introduced an outdoor gym, what caused spatial disturbance of view point. Unfortunately, pavements and urban details in this area need to be modernized or replaced (Figs. 1, 2).

Fig. 1. Park Morskie Oko, Warsaw (photo by K. Pluta, 2016)

Fig. 2. Park Morskie Oko, Warsaw (photo by K. Pluta, 2016)

The second part of the present Morskie Oko Park is the **Mokotów residential complex**, which forms **the park with Szuster Palace** (from which the original classicistic palace "Mon Coteau" of Izabela Czartoryska Lubomirska was named Mokotów district, designed by Efraim Schroeger 1772–1774, rebuilt into neo gothic villa for Potocki, designed by Henryk Marconi 1822–1825; on the upper level – geometrical garden designed by Szymon Bogumił Zug 1848, on the lower level – natural composition of the garden). During World War II park trees were destroyed and the palace was burned out in 1944, only a Moorish little house and pigeon-house survived. After the war in 1966, Szuster Palace was rebuilt for the Warsaw Musical Society (designed by J. Brabander), preserving the former layout of the composition of the garden [8, p. 114–122, 11, p. 111].

This is another interruption of the eastern frontage of Puławska Street by a 100-m long green space, on the axis of which is Szuster Palace, picturesquely situated at the edge of the escarpment. Together with the green system, subordinated to the main axis, it is the architectural spatial dominant on the escarpment. On the main axis of the complex near Puławska street there was located in 1995 Monument of Jan Matejko (designed by Marian Konieczny, 1989). Unfortunately, the entire complex is in a state of great negligence and requires a revalorization, especially the following spatial elements: the terrace near the palace on the slope side, ramps on both sides of the palace, main axis of the park on the western side. Main actions should include: new development of low greenery of the terrace and main axis, replacement of pavement alleys and replacement of urban details (mainly benches) (Figs. 3–5). The park at the lower level (of natural composition layout, including organic alley shapes, groups of different species of free layout trees, green interiors formed on the basis of water reservoirs), also requires modernization activities (replacement of alley pavements and urban details – benches and lighting, cleansing the pond, better maintaining of grassy surfaces with a possible new composition of low greenery).

Fig. 3. Residential complex Mokotów, Warsaw (photo by K. Pluta, 2016)

Fig. 4. Residential complex Mokotów, Warsaw (photo by K. Pluta, 2016)

South of **St. Michael Church** Puławska street runs on a short sector among park greenery situated for the first time on both its sides: from the west side General Gustaw Orlicz-Dreszer's Park, and from the eastern side the green of Małkowscy Square, starting the greenery of a large landscape complex and at the same time a sport club "Warszawianka" with an important view point on its territory. The sport complex SKS "Warszawianka" was established in the 1960s according to the design of Jerzy Sołtan. It is an unusual example of the inclusion of terrains and sport facilities in the topography of the escarpment and lower terrace [8, p. 114–122].

General Gustaw Orlicz-Dreszer's Park – a modernist layout, was founded during the presidency of Stefan Starzyński in the fortress moat of the former Mokotowski Fort (designed by Z. Hellwig, in the studio of L. Danielewicz, June 26, 1938). The park was designed as a walk and recreational park on a rectangular plan with a central alley as the main compositional axis. The park area consisted of three geometrical park interiors of different character and green walls with regular vegetation (interiors are separated by compact groups of coniferous trees on both sides of the axis). The composition of the park enriches the chestnut-tree alley in oval shape, located in the eastern part of the park [11, p. 138–139].

During Warsaw Uprising there were heavy fights in this part of the city and the park was severely destroyed and became one of the largest provisional cemeteries. The park was renovated in 1951 (restoration of the former axial composition system), in 1989 it was entered into the register of monuments, and in 2007 a comprehensive revalorization of the park was completed. A monument of "Mokotów fighting 1944" was situated in the park (the cracked boulder is a monument of inanimate nature – the gray granitoid), where the annual anniversary of Warsaw Uprising begins on August 1 every year. At present, after the revalorization, the first interior in the park was complemented with sculptures; in the second interior, besides the monument, there is a new playground with a summer cafe (both functions on the other side of the axis); and in the third interior there was proposed special composition of floral ground-floor and a new fountain on the main axis. It should be emphasized that the quality of all pavements of alleys and urban details (benches, lighting, baskets) as well as of low greenery is very high. During summer the park hosts jazz concerts and other cultural events (Figs. 6–9).

Fig. 5. Residential complex Mokotów, Warsaw (photo by K. Pluta, 2016)

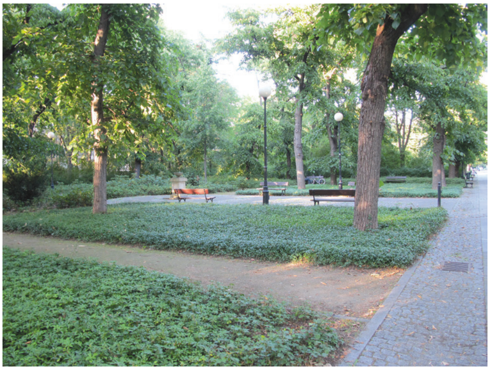

Fig. 6. Gustaw Orlicz-Dreszer's Park, Warsaw (photo by K. Pluta, 2016)

Fig. 7. Gustaw Orlicz-Dreszer's Park, Warsaw (photo by K. Pluta, 2016)

Fig. 8. Gustaw Orlicz-Dreszer's Park, Warsaw (photo by K. Pluta, 2016)

Another explored **residential complex is Królikarnia** – one of the most valuable palace and park complexes shaped in the second half of the 18th century on the area of Warsaw Escarpment (Figs. 10, 11) The complex is also one of the most important spatial types of architectural and garden systems existing in the escarpment area (a system based on the connection with artificial water reservoirs beneath the slope – due to the considerable distance of the river from the escarpment). The name of the residential complex Królikarnia is derived from the rabbit farm belonging to King August II Mocny in the early 18th century. Near the complex there is situated **Arkadia Park** (founded in 1968–1970 according to the design of Longin Majdecki, the upper and lower parts with pounds are connected by a staircase system) (Fig. 12). In the explored area the escarpment creates an unusually picturesque landscape with numerous ravines, ponds on the lower terrace and greenery, shaping the interiors and view closes and reflecting in the water plane. At this place, the escarpment is unfortunately very far away from the river (about 5 km). The Królikarnia complex was shaped at the site of changes of the escarpment line, in contact with the edge of ravines in order to increase view values of the place. The complex consists of the following elements: the upper garden,

Fig. 9. Gustaw Orlicz-Dreszer's Park, Warsaw (photo by K. Pluta, 2016)

Fig. 10. Residential complex Królikarnia, Warsaw (photo by K. Pluta, 2016)

Fig. 11. Residential complex Królikarnia, Warsaw (photo by K. Pluta, 2016)

Fig. 12. Park Arkadia, Warsaw (photo by K. Pluta, 2016)

the palace at the edge of the escarpment – determining the main axis of the complex, and the lower garden of a free composition. The palace, situated on one of the hills between the ravines, forms with its greenery one of the most beautiful architectural spatial dominant on the escarpment (classicist palace designed by Dominik Merlini 1782–86, the 18th-century landscape park, rebuilt in the nineteenth century, the reconstruction of the palace according to the design of Jan Bieńkowski 1959–1964, reconstruction of the garden according to the design of Gerard Ciołek 1962 – according to layout of the garden from the middle of the 19th century, cleaning works in the park according to the design of Longin Majdecki 1967–1969) [9, p. 291–299; 5, p. 213; 11, p. 114–118].

Both in the palace project as well as in the kitchen project it is possible to find European cultural influences from various periods: the kitchen is a round building – modeled on the Tomb of Cecilia Metellia in Rome in Via Appia (a circle plan in the form of picturesque ruin), while the palace is a classicist suburban villa (centrally planned building on the square plan with circular living room in the middle, covered by dome on the drum, double floor with high ground-floor and extraordinary portico) – referring to the renaissance villa

"Almerico-Capra" called "La Rotonda" near Vicenza (designed by Andrea Palladio, 1550) [2, p. 71–72].

Until the 1920s, the complex was still a suburban residence. The complex of Królikarnia was severely damaged during the Second World War: the palace was burned and destroyed in September 1939 and then the kitchen was burned during the Warsaw Uprising in 1944, the terrace with grotto and park trees were destroyed. After the war the palace was rebuilt, the interiors of the palace were partially rebuilt, and the palace was dedicated to the seat of museum of sculptor Xawery Dunikowski (now it is the National Museum Branch in Warsaw).

At present, the public space of Królikarnia complex is very often the place of various exhibitions, performances, concerts and multimedia shows. The interior of the oval alley in front of the palace on the western side is filled with lawn and single trees, which are unusual spatial accents. This vast empty space, which is a magnificent observation plane of facade of the palace, is surrounded by a massif of leafy trees of various species. Along the oval alley, there are situated various sculptures, which are a permanent exhibition in the park (Sculpture Park). The reconstructed terrace also has small scale sculpture elements. From the terrace of the palace there is an extensive view for the ponds, park greenery, allotment gardens, residential buildings, multi-family housing estates and forests on the horizon. Unfortunately, this view is increasingly narrowed by overgrown greenery. At the same time, the view is dominated by objects or groups disturbing the harmonious landscape, such as "Siekierki" heating plant and power station complex with high chimneys. The complex was partially fenced – outside the fence it is a northern gorge and a part of the park with ponds. This resulted in the division of the complex into parts available temporary (located higher) and the part available without a restriction (located lower). Between these two parts, there are view connections and links by alleys in both ravines. Two artificial ponds located on the axis of the complex are separated by a dam. The positive changes of the landscape of the complex include: revitalization and modernization of the lower part of the park and the neighboring and associated directly with it Arkadia Park (replacement of surface pavements from hardened to biologically active, new composition of low greenery, cleansing of ponds, new elements of small architecture – benches, rubbish bins, lighting in both parks). There is also a children's playground and an outdoor gym near the north avenue. On the other hand, there are also negative changes in the landscape of the areas adjacent to the complex, caused by strong investment pressure, the growth of motorization and air pollution and the increase in noise intensity.

4. Summary

The explored complexes are an important heritage of the Polish nation and are a valuable examples of European cultural influences. These are places where nature harmoniously meets culture, history meets contemporaneity, preservation of values of environment and cultural heritage meets contemporary spatial transformations.

Contemporary spatial composition of historic architectural-garden systems and urban parks in the area of Warsaw Escarpment in the district Mokotów refers to carefully composed landscape of original projects to a large degree, and emphasizes the most valuable characteristics of the place. However, there are also many spatial transformations of the study areas as well as of the areas located in the immediate vicinity. These transformations are both positive and negative. Among the negative phenomena it is necessary to mention: negligence of areas, including low quality of urban details, pavement and low greenery, narrowing of valuable views by overgrowing high greenery and random modern use, lack of processes of revalorization of some systems and their fragments, strong investment pressure on areas in the immediate vicinity, air pollution and the increase in noise intensity caused by the growth of motorization. Among the positive changes it is necessary to mention contemporary attempts of shaping and use of public spaces in parks and complexes, together with the processes of revalorization of different areas and elements (including low greenery, surface of alleys' pavement and small architecture), introduction of positive elements of contemporary development (such as playgrounds, sports facilities).

The desire of protection of these unique spatial complexes and urban parks creates the need to reconcile protection of their natural and cultural heritage with the emerging new needs of a dynamically developing European city.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017
ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.17.168.7276

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Contemporary development concepts for the escarp of the pomeranian dukes' castle in szczecin

Współczesne koncepcje zagospodarowania skarpy zamku książąt pomorskich w szczecinie

Abstract

The Pomeranian Dukes' Castle in Szczecin forms one of the most characteristic elements of Szczecin's cityscape. That is why it is extremely important to expose its values properly, to stress the solid of the castle in the city panorama, according to its historical condition. Modern concepts for development of the northern castle escarp do not always meet the above expectations, both when it comes to composition and the very geotechnical safety of the escarp. The contemporary concepts for the development of northern escarp of the Castle Hill in Szczecin were presented in the paper, on the background of the complex historic, compositional and also technical conditions.

Keywords: revalorization of historic gardens, castle gardens, Pomeranian Dukes' Castle in Szczecin

Streszczenie

Zamek Książąt Pomorskich stanowi jeden z najbardziej charakterystycznych elementów krajobrazu miasta Szczecina. Dlatego też niezwykle istotne jest odpowiednie wyeksponowanie jego walorów, podkreślenie bryły zamku w panoramie miasta zgodnie z uwarunkowaniami historycznymi. Istniejący sposób zagospodarowania północnej skarpy zamku zarówno nie spełnia powyższych wymagań kompozycyjnych, jak i nie zapewnia bezpieczeństwa geotechnicznego dla bryły budowli. W artykule przedstawiono współczesne koncepcje zagospodarowania północnej skarpy Wzgórza Zamkowego w Szczecinie na tle złożonych uwarunkowań historycznych, kompozycyjnych, a także technicznych.

Słowa kluczowe: rewaloryzacja zabytkowych ogrodów, ogrody zamkowe, Zamek Książąt Pomorskich w Szczecinie

1. Introduction

The Pomeranian Dukes' Castle, apart from the Hakenterrasse forms one of the most characteristic elements of Szczecin's panorama from the bank of Odra river. The Castle is also the most prominent landmark of the Old Town, strongly defining the identity of that place [8, p. 52], which was largely damaged by Allied bombing and introduction of foreign elements during postwar reconstruction. Still the solid of the building in the panorama from the north (main city entrance through Trasa Zamkowa [Castle Route]) is effectively obscured, at least for most of the year, by the trees growing on castle hill escarp. Even if analysis of iconographic documentation did not prove the existence of high-growing plants on the northern escarp, the problem of unveiling the castle vista is a more complex one. It is a basis for discussions of the manner in which this place should be developed for over ten years till now [4, 15].

The aim of the paper is to present, on the background of the complex historic, compositional and also technical conditions, the contemporary concepts for the development of northern escarp of the Castle Hill in Szczecin.

2. Pomeranian Dukes' Castle in Szczecin – historic development

The Pomeranian Dukes' Castle is located in the oldest part of Szczecin, on left bank of Odra River. Archeological research proved, that a borough was first built on today's Castle Hill in last period of Lusatian culture, namely in the Hallstatt period. The perfect defensive properties of the hill that rises some 20 meters above the waters of Odra River and is embanked by ravines with streams flowing in their bottom, at a place where river crossing was also possible were decisive in starting a defensive settlement there [1, p. 25]. The excavations revealed fragments of borough embankments and permanent housing [2, p. 284–285]. When in 967 Mieszko I of Poland included the Odra estuary in his Piast state Szczecin was made of a defensive borough located on a terrace at Odra, lowest town located between the terrace and Odra River, a harbor and a small burgh. The main borough included a temple of Triglav, who was worshipped by pagan population till 12th century. In 1346 Duke Barnim III started the construction of his new seat. The "Steinhaus" – stone building some 30 meters long, 10 meters wide and 8 meters high replaced the old borough. To the west of the building there was a chapel of St. Otto, surrounded with walls. The second wall, almost 4 meters high, surrounded the whole development.

In the 15th century Duke Bogusław X modernized the southern wing and two towers, and in 1538 his son, Barnim XI – while reconstructing the development after a fire – raised the "New House" by one storey and constructed the octagonal parts of towers. The highest southern wing thus had a rarely seen height of 30 meters, had 4 levels and its length was 52 meters. Duke Bogusław X's reign initiated the golden age of the castle – the duke was an ambitious ruler, educated in Cracow by Jan Długosz and married with daughter of Polish King – Anna Jagiellonka. He was the one to unite Western Pomerania. His son, apart from modernizing the southern wing, also constructed the eastern one. In the second half of the 16th century, during the reign of Duke John Frederic, the castle became an impressive renaissance residence. In the years 1571–1581 the construction was supervised by Wilhelm Zacharias – an Italian architect [11, p. 67].

At the end of 16th century the church was demolished, together with the "Steinhaus" and the buildings in the western part of castle, and northern and western wings constructed in their place. The wings now had equal height of three levels and were topped with a continuous attic. Vast castle yard with sides measuring 50 meters was surrounded by cloister. The castle was continuously enriched with new works of art. In 1616–1619 fifth wing of the castle – the mint wing that was to hold the library and museum that could accommodate the collection gathered by Philip II, brother of the last duke – was build. After Duke Bogusław XIV died in 1637 the castle became the residence of Prussian Governor Bjelke. In 1648 Western Pomerania was divided in the result of an agreement between Sweden and Brandenburg, Szczecin was retained by Swedes. The Duchy fell and the subsequent owners of the castle did not sufficiently care for it – the reconstructions decreased the artistic value of renaissance details. During wars with Sweden the castle and the city were largely damaged in 1677. The residence was shelled by artillery, with the northern wing completely destroyed and the remaining ones largely damaged. Swedes conducted repair works according to the design of Johan Frederik Gothe. The castle hill has since become seat for military [7].

In 1713 the castle was besieged by army of the anti-Swedish coalition and the artillery shelling once again significantly damaged the walls of the building. In 1720 the city was included in Prussian borders. The residence was subjected to construction works that finished in 1736: the interiors were only slightly altered, but the elevations completely changed, the Philip II museum wing and the castle roofs rebuilt. In 1806 the castle witnessed the entry of Napoleon's army and after his defeat in 1813 Szczecin came back in Prussian hands. During the 19th century the structure was gradually rebuilt: with a court, administrative offices and archives located in its interiors.

Prussian times (1713–1945) saw the largest neglect of the castle. It housed an arsenal, numerous offices and even a brewery in that period. Its equipment was transferred to Berlin and the reconstructions of 1736 and 1872–1874 further contributed to lowering its architectonic value. The castle hill was surrounded by residential buildings making the structure almost invisible [16].

It was not until early 20th century that ideas of returning the castle to its former glory appeared. In 1925–1926 some renovation and ordering works were conducted, but the slow progress of plans was halted by the Second World War. Germans installed anti-aircraft guns on tops of the castle, making it one of the primary targets for bomb raids. Allied bombings in the last phase of war (mainly in spring of 1943 and on August, 17, 1944) totally destroyed Szczecin's Old Town and the castle [1, p. 233–234]. What remained from the former residence of Dukes of Pomerania were damaged walls, most of the ceilings collapsed.

The reconstruction of Old Town was not started immediately after the war, due to extent of the damages. At first the less damaged districts were rebuilt [1, p. 234–236; 3]. Between 1945 and 1951 mainly stocktaking and securing works took place. Rebuilding only started in 1958, based on designs by Professor Stanisław Latour. The wings of the structure were to house a Culture Center, a chamber orchestra hall, castle restaurant and exhibition halls. The southern wing was to house a Musical Theatre (now the Castle Opera) and Marriage Hall of the Register Office, the mint wing – Historic Monument Reconstruction Works (currently the seat of the Marshal's Office) [9].

Negative transformations of landscape directly neighboring the castle occurred right after the war, when in 1947–1949 the Odra side bypass was constructed on the bank of Odra river. A wide boulevard was erected on the ruins of the lower Old Town houses, making place for four lane carriageway and tramway rails. This completely destroyed the oldest urban system of the Old Town located at the river [1, p. 234], and also functionally and compositionally "cut off" the city from Odra river. Another investment in that area – construction of the Castle Route (Trasa Zamkowa) in 1996 contributed to total degradation of vista properties of the Castle Hill from north-western side. The castle, together with the medieval Tower of Seven Coats at its base was virtually surrounded by serpentines of the overpass – main entrance road to the city (Fig. 1). The panorama of castle and the Old Town visible from the northern side of the river and from the riverside was irreversibly distorted.

To find out, if the castle hill was built over or if there were composed garden with trees and bushes in the past – there was the analysis of preserved iconographic documentation conducted by the author of the present paper.

Fig. 1. The Pomeranian Dukes' Castle in Szczecin seen from the riverbank, May 2017
(photo by M. Rzeszotarska-Pałka)

3. Castle gardens

Castle gardens were characteristic in particular in Middle Ages, when they were started in connection with the castle's solid, as enclosed garden interiors, frequently in shape of rosary or a small utility garden. In Renaissance in turn, the gardens were composed in quarter form and frequently were stretching outside the area enclosed by fortifications. Polish examples of renaissance castle gardens include: decorative garden enclosed by walls and the Italian garden started by Queen Bona on terraces of Wawel, a quartered garden along the fortress curtains in Zamość, vegetable and flower quarters at Łodygowice castle and gardens that were located outside fortress walls in Łowicz and Wiśnicz [13, p. 291–292].

Unfortunately both literature and archive documentation lack any information about the development form for both courtyards and castle hill scarp in Szczecin in the times of its greatest glory in Renaissance and also in later period. Some more information is brought by iconographic sources [5]. Map from the 1581 work by Georg Braun and Frans Hogenberg entitled *Civitates orbis terrarum* shows a narrow northern scarp of the castle devoid of any plants and ending with a high defensive wall and a moat at its base, filled with low-growing plants. The 1641 *Stetinum* engraving by Matthaeus Meridian also shows no plants nor terraced shaping of the northern escarp of the castle hill (Fig. 2). The chaotically located residential and commercial buildings, and low trees and plants are visible in the 1826 *Schloß Stettin von der Mitternachtsseite* painting by August Ludwig Most. Similarly, the next painting – *The Vista of Szczecin from* Łasztownia *Shipyard* of 1847 shows the panorama of Old Town with perfectly visible solid of the castle that is not covered by any greenery.

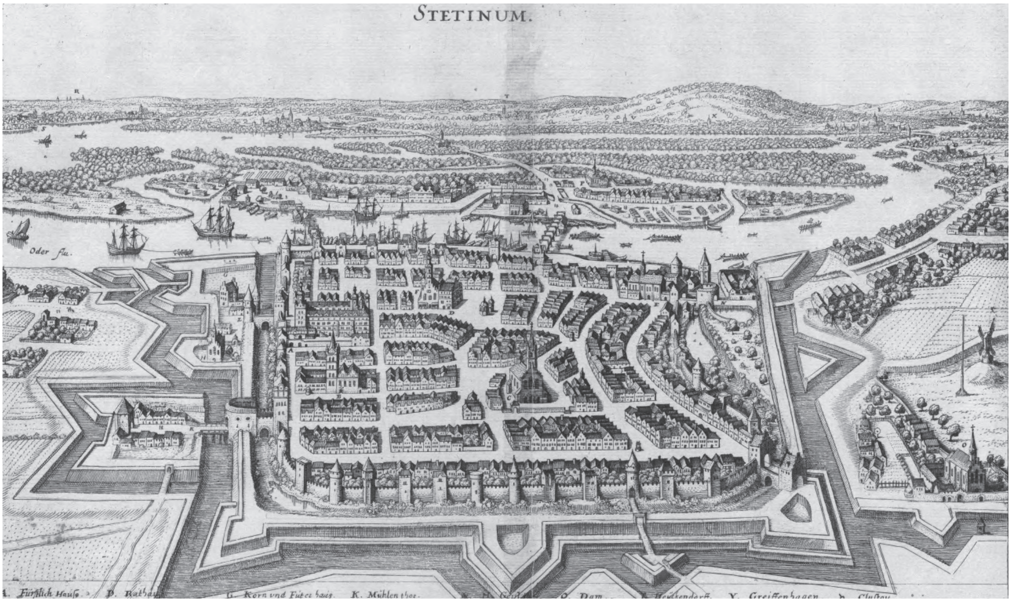

Fig. 2. Matthaeus Merian, 1641, *Stettinum*, Frankfurt a.M., copperplate, T. Niewodniczański collection, Syg. Ikn. 150N, open access, https://fbc.pionier.net.pl/details/nnhm3ng (access 15.05.2017)

To summarize the above – the analysis of preserved iconographic sources reveals, that in 19th century the castle hill was built over at its base with townhouses. The escarp also shows some trees and bushes, but they do not obstruct the castle's solid and are not a dominant element, just supplementing the existing buildings. We also found no traces of purposefully composed garden terraces on castle escarp.

4. Development concepts for the escarp of the Pomeranian Dukes' Castle in Szczecin

The Pomeranian Dukes' Castle has permanent place in spatial structure of the city and the awareness of its inhabitants, both former and present – forming a recognizable element in Szczecin's landscape. Still its solid remains covered by chaotic plantations on its northern escarp. Trees growing in that place are mostly self-sown, and introduced after the war. Even with some being 50 or 60 years old, they do not form a devised composition that would stress the castle's solid, nor are they made of valuable species. Dendrological inventory of the northern escarp of the Pomeranian Dukes' Castle in Szczecin, which was carried out in 2012 revealed: norway maple (*Acer platanoides)* – 53 pieces, false acacia (*Robinia pseudoacacia)* – 28 p., ash (*Fraxinus excelsior)* – 27 p., wych elm (*Ulmus gabra)* – 13 p., sycamore (*Acer pseudoplatanus)* – 8 p., black elder (*Sambucus nigra)* – 5 p., holly (*Ilex aquifolium)* – 3 p. [12]. Furthermore – they effectively obstruct the castle panorama from north during the vegetation period – from the side of Castle Route (Trasa Zamkowa), Solidarności Square or Korsarzy Street the sole visible element is the Bell Tower (Fig. 3). Only in winter, when the trees have no leaves we can admire the silhouette of the northern wing, although slightly obscured by mosaic of boughs and branches.

The idea of cutting down the trees growing on the northern escarp appeared already in 2006 and won positive opinion of the Regional Historic Monument Conservation Office (WUOZ). According to Ewa Kulesza of WUOZ the castle should be unveiled, and the moat running at the base, overgrown at that time, turned into a walking path. This idea was also supported by professor Stanisław Latour, who rebuilt the castle from war damages: "The greenery in the northern escarp is totally random, abandoned, obscures the castle and it requires intervention. Even when there is no permit to cut it down completely it should be decisively thinned out and ordered. So that the escarp does not bring us shame" [15].

Still the 2010 geotechnical expertise proved that possible earthwork that would change the shape and ecosystem of the escarp could be detrimental [14]. The escarp is made exclusively from non-homogenous made ground, still its condition is currently stable. This is also fostered by the root system of the trees growing there, that plays the role of anchors, and the fact that trees take their water from the ground secures low soil humidity. The permeable soils of the escarp are the gravitational flow path for ground waters towards Odra river, thus the removal of trees would intensify this process and could trigger landslides. Caution was advised in changing the development of that area. It was deemed necessary only to remove the less valuable, unhealthy trees and to absolutely leave the trunks in the soil, with their stabilizing

Fig. 3. The Pomeranian Dukes' Castle in Szczecin covered with trees – view from the side of Castle Route (Trasa Zamkowa), May 2017 (photo by M. Rzeszotarska-Pałka)

function replaced over time with newly planted plants. The experts also ascertained that it is not recommended to introduce such changes in the shape of the escarp that would increase its steepness or load [14, p. 7–8].

Discussions on idea of "unveiling" the castle did not stop and in 2011 the Zakład Usług Komunalnych in Szczecin announced a contest for design of development of the northern escarp. There were four submissions, but the Contest Committee decided that none of them fulfilled expectations – according to Ewa Stanecka, the regional conservator of historic monuments the designers failed to recall the historic character of location, modern plant structures were proposed, and not all of them were adjusted to steep escarp. And most of all none of these works did anything to expose the values of the castle and stressed its silhouette.

The castle management adopted a decision to order the development of castle hill development. The concept was developed in 2016 by the Szczecin-based *Compono* architecture company. According to them the trees were to vanish from the northern escarp, replaced by lower plants and footpaths on four different levels, composed in resemblance to the renaissance quartered gardens. After cutting tall trees the design envisages the removal of clay and rubble deposits from the scarp and their replacement with reinforced concrete structure to secure their stability. It is worth stressing that the planned pseudo-renaissance terraces never existed in that place and have no historic justification.

The castle management stated that the design of terraces would be completed within two next years, but in the light of recent events thee plans are now questionable. As this paper was drawn (in May 2017) in northern wing of the Pomeranian Dukes' Castle in Szczecin fragments of ceilings from the second floor down to the cellar collapsed. The reason for ceiling collapse was structural support of the ground floor falling below cellar level. Currently the object is closed for visitors and the area of building disaster is secured and investigated. Experts list unstable ground underneath the cellar as potential cause, and whole escarp cross-section contains such [6].

The issue of development of greenery areas around an object as important as the Pomeranian Dukes' Castle in Szczecin also became subject of many concept works developed during the *Revalorization of historic gardens* classes at the faculty of landscape architecture of ZUT in Szczecin. Various concepts with common aim of exposing the castle silhouette were developed under supervision of the author of the present paper. Some of them envisaged complete cutting out of the existing trees, assuming the absolute necessity for stabilization of the escarp with a system of reinforced concrete poles and foundation slabs, with differently composed terraces on top of them – from a style that resembles the renaissance quartered gardens (Fig. 5) to the more modern proposals of walking alleys going gently down the escarp. In other works the students proposed less radical solutions, assuming leaving the existing trees in the lower zone of escarp (following the recommendations of the geotechnical survey), only exposing the castle silhouette (Fig. 4).

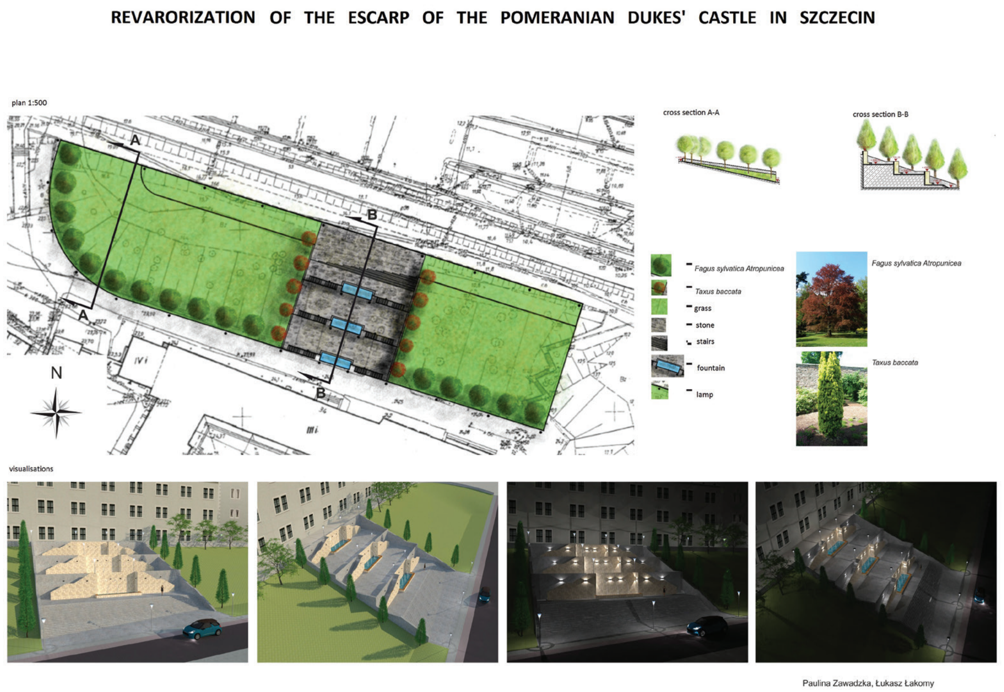

Fig. 4. Revalorization of the escarp of the Pomeranian Dukes' Castle in Szczecin, authors: Ł. Łakomy, P. Zawadzka under the supervision of M. Rzeszotarska-Pałka, ZUT in Szczecin 2014

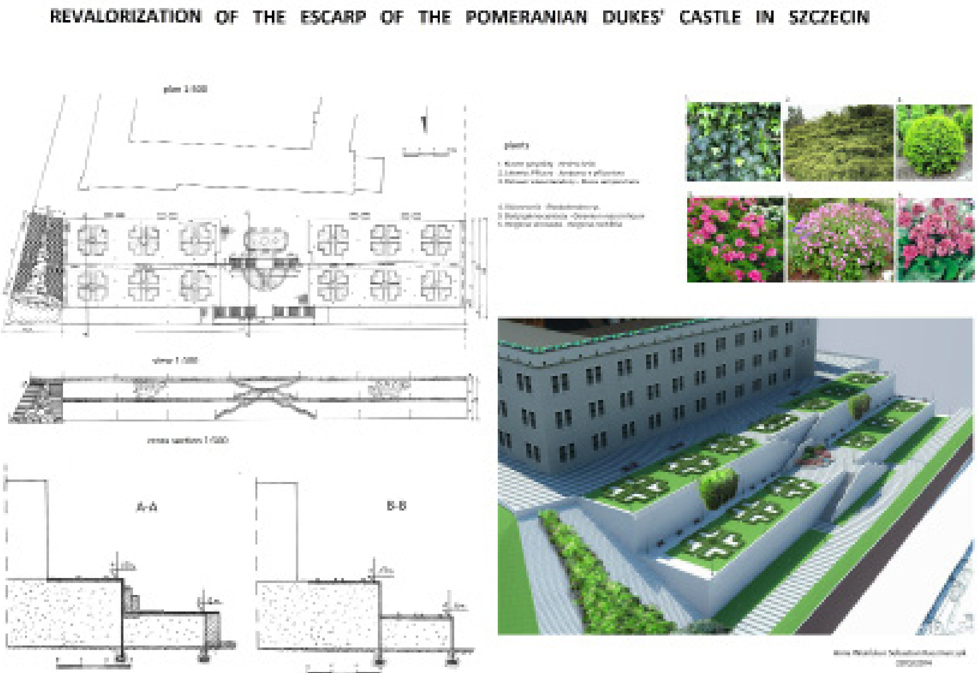

Fig. 5. Revalorization of the escarp of the Pomeranian Dukes' Castle in Szczecin, authors: A. Wisińska, S. Kaczmarczyk under the supervision of M. Rzeszotarska-Pałka, ZUT in Szczecin 2014

5. Summary

Lack of expressiveness and legibility of space, but also loss of characteristic elements that decide about the identity of cityscape is a problem of modern cities [10, p. 143]. Without any doubt the Pomeranian Dukes' Castle in Szczecin is a unique element in the cityscape that defines its character and is recognizable by both inhabitants and people from outside Szczecin. That is why it is extremely important to expose its values properly, to stress the solid of the castle in the city panorama, according to its historical condition. Modern concepts for development of the northern castle escarp do not always meet the above expectations, both when it comes to composition and the very geotechnical safety of the escarp. It seems that finding an optimal solution of this problem still requires deeper studies and common analysis of specialist from different fields: landscape architects, engineers, geologists, historians and monument conservators. The concept works (with common aim of exposing the castle silhouette) developed under supervision of the author of the present paper at the Department of Landscape Design of ZUT in Szczecin could be also used in further studies.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017
ARCHITECTURE AND URBAN PLANNING
DOI: 10.4467/2353737XCT.17.169.7277

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Shaping of the living environment of the elderly and its relations with the surrounding areas upon the example of Copenhagen

Kształtowanie środowiska życia osób starszych i jego relacji z otoczeniem na przykładzie Kopenhagi

Abstract

This paper demonstrates the possibilities of shaping of the living environment of the elderly in connection with the existing urban tissue according to the principle of inclusion in the space used together with the younger generation.The subject matter of the analysis are selected examples of Danish architectural and urban projects implemented in Copenhagen over the last decade. Denmark is one of the leading European countries in terms of its policy towards seniors and shaping of the living environment of elderly people.

Keywords: architecture, urban design, living environment of the elderly

Streszczenie

W artykule zaprezentowano możliwości kształtowania środowiska życia osób starszych w powiązaniu z istniejącą tkanką miejską na zasadzie włączania w przestrzeń wspólnie użytkowaną z młodszymi pokoleniami. Przedmiotem analizy są wybrane przykłady duńskich realizacji architektoniczno-urbanistycznych, które powstały na terenie Kopenhagi w ostatniej dekadzie. Dania należy do krajów o dużych osiągnięciach w zakresie polityki senioralnej, a także w zakresie kształtowania środowiska życia dla osób starszych.

Słowa kluczowe: architektura, urbanistyka, środowisko życia osób starszych

1. Introduction – demographic processes and senior policy of Denmark as factors deciding on the shaping of the housing environment for elderly people

The objective of this paper is to demonstrate the possibilities of shaping the living environment of the elderly in connection with the existing urban tissue according to the principle of inclusion in the space used together with the younger generation[1]. The subject matter of the analysis are selected examples of architectural and urban projects implemented in Copenhagen over the last decade, inscribed in the principles of universal design[2].

Making use of the experience of Denmark in the scope of the subject matter of this paper is justified byits accomplishments in terms of the senior policy. It should be also added that this country occupies one of the leading positions in terms of expenses incurred for healthcare and social welfare amongst European states[3].

The concepts of shaping of the living environment of elderly people presented herein and their relationships with the urban space constitute an attempt by their designersto answer the demographic processes and changes in the social structure of Denmark observed in recent years. Hence,a brief characterisation of these processes and of the state policy relating to them is provided below.

In Denmark, similarly to other European countries, for several decades now the process of the aging of the society has been observed. It manifests itself in the growing number of elderly people and the simultaneous drop of the share of the youngest age groups in the demographic structure[4]. In different regions of the country this process is uneven.

The population of the country as of today is 5,750,000. 19% of this number are people aged more than 65, and ca. 4% are people aged more than 80 [10]. Forecasts for 2040 assume that the population will rise to 6.3 m, 25% of which will be constituted by a group of people aged 65 and more[5].

At the same time, in Denmark, similarly to all Scandinavian countries, a phenomenon of constant growth of the length of life of the country's inhabitants becomes clearly marked. Additionally, they enjoy good health and condition much longer than inhabitants of other European countries.

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1 In this paper the terms 'elderly people' and 'senior citizens' are used interchangeably. It is a social group which is economically heterogeneous, diversified in terms of lifestyle, education, health condition. The common determinant of 'an elderly person' or 'a senior citizen' is old age.

2 Universal design – philosophy of designing products, buildings, and their surrounding areas so as to make them possible to be used by all people in as broad a scope as possible, without the need to adapt or design them in any special way.

3 The state allocates to this purpose nearly twice as high a percentage of GDP as Poland does.

4 Different measures and classifications allowing to evaluate the progress of aging of the society are used in demography. Studies concern the share of people aged 60 and more in a specific population and quantitative relations between basic age groups (children: aged 0–14, adults: aged 15–64, the elderly: aged 65 and more). These studies aim to determine intergenerational relations in the society and to evaluate the level of demographic old age. Owing to the advancements in medicine and prolonging life expectancy, the threshold of old age is usually assumed to be 65 and morein the subject literature [5].

5 It is assumed that the threshold of the demographic old age for a given country is determined by the following data: 12% of people aged 60 and more or 7% of people aged 65 and more [4, p. 5].

Changes occurring in the demographic structure, particularly the growing share of the oldest age groups, have their effect on decisions of the authorities referring to the directions of the senior policy, economic policy, space shaping policy, social and migration policy.

The senior policy is the cutting edge of the directions of activities undertaken by public administration of the state, as well as of different organisations and institutions whose goal is to promote decent and active life of senior citizens. It is based on national recommendations, as well as on recommendations contained in international documents. In this respect one should mention the Madrid International Plan of Action on Aging (MIPAA, Madrid, 2002) and the Regional Strategy of Implementation of International Action Plan on Aging (UNECE Regional Implementation Strategy RIS, Berlin, 2002), planned to be implemented by European states.

Within the scheme of implementation of the recommendations contained in the latter document, the Danish government undertakes actions covering 10 areas in the adjustment to the aging processes of societies. These are: 1 – adjustment of social and economic policy to demographic processes, 2 – securing full integration and participation of elderly people in social life, 3 – promotion of sustainable economic development, 4 – social protection, 5 – adjustment of the labour market and promotion of professional activity, 6 – promotion of training and continuing education, 7 – securing well-being and good quality of life at any age, 8 – equal opportunities for women and men, 9 – supporting families taking care of the elderly and intergenerational solidarity, 10 – promoting regional cooperation in terms of implementation of the policy for the benefit of the elderly [11, 6, p. 19–20].

Within the scheme of the senior policy, it is assumed that the forecast growth of the oldest group of citizens (aged 80 and more) constitutes most of all a challenge for the healthcare and social welfare system. Therefore, considerable importance is attached to the development of various medical services, in particular in the sector of long-term care. The state's support in this respect is necessary because informal carers play a relatively small role in the Danish care system compared to other European states[6]. It should be emphasized that the elderly take part in the decision-making process within the scheme of the senior policy by their activities in organisations that operate according to the principles of voluntary services promoted and supported financially by the state[7].

The senior policy is also directed towards the creation of a diversified housing offer for elderly people, which fosters their activity, the process of establishing social relations, and which prevents isolation in the urban space. Seniors individually decide about the type of household they wish to have, depending on their degree of independence and state of

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6 In developed countries long-term careis understood as all medical and social measures, with different distribution of responsibilities of both sectors. Its broader definition is provided by WHO, describing it as an integral part of healthcare, relating to activities for the benefit of people in need, implemented by informal carers (relatives, friends, neighbours), formal carers (including medical professionals and social workers), as well as by traditional carers and volunteers. According to: Actual State and Perspectives for Development of Long-Term Care in Poland, Ministry of Health, Warsaw, December 2012, p. 4.

7 The most important of them are: the Dane Age Association (600,000 members) and the Danish Association of Senior Citizens (330,000 members).

health[8]. The offer comprises the opportunity to live e.g. in houses with apartments adjusted to the needs of senior citizens, in housing cooperatives, in apartments with an assistant, in nursing homes, or to benefit from services provided by day care centres[9]. These centres are addressed to people who use medical and care services, therapies and all sorts of activities on a temporary basis. The analysis of the latest projects allows the directions and tendencies currently emerging in the process of shaping of housing environment for the elderlyto be determined[10]. In general, it can be assumed that the process consists in the search of the closest possible relationships between this community and the existing urban tissue in order to create relations with other social groups. These relations are discussed in more detailed below, on the basis of an analysis of selected examples.

2. Activities aiming to create mutual bonds between inhabitants and their relations with the urban environment – examples of specific solutions

The examples presented below constitute projects implemented within the territory of the capital city of Denmark. This choice is justified by the fact that Copenhagen belongs to the group of the friendliest places for living in Europe due to the standards of urban public spaces, the organisation of transport, and the quality of the natural environment, as well as of the housing environment. Harmonious development of the urban space results from activities, consistentlyimplemented for decades now, which aim to increase the comfort of living of the city inhabitants. The high quality of medical and care services and promotion of a healthy and active lifestyle are also essential for their sense of well-being. It should be added here that the capital of Denmark strives to reach the position of a leader in creatinga model sustainable city (Eco-Metropolis) amongst metropolises globally.

Copenhagen is the largest Danish city and its population is ca. 600,000. Compared to the population of the country, as well as other capital cities of the European Union, it is characterised by theyoung age structure of its inhabitants. The metropolitan region also has the highest percentage of people in the productive age (20–64). People aged 65 and more constitute 10.3% of the city population[11]. Forecasting the further growth of this group of city inhabitants, the city is preparing a strategy so as to stimulate their activity, as well as their intra- and intergenerational cooperation. The priority of this strategy is an assumption that

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[8] In 2006 ca. 5% of Danish people aged 65 or more were covered with long-term care at home, whereas 9.5% of them were covered with care provided by institutions (nursing homes) [7].

[9] Nursing homes function as conventional, subsidised, or non-profit entities.

[10] Living environment of the elderly – this term comprises housing environment as the most important place of living, and urban space, used by elderly people irrespective of their health condition, age, lifestyle, family situation, individual interests. The term 'housing environment' as used in this paper comprises most of all a house, an apartment, an adjacent area (micro-housing environment). Relations between the housing environment and the urban space as used in this paper refer to relations with:

- The space of a housing estate, a district along with services and green areas (broader housing environment)
- Space of the city, with its services, public space, and transport (macro-housing environment).

[11] Data for Q1 2017: StatisticsDenmark [10].

elderly people should remain in their homes as long as possible, with access to all forms of assistance. In the case of making use of institutional forms of care in the city, in nursing homes addressed to senior citizens, they are usually located close to services and housing developments addressed to other generations. This principle is implemented by e.g.:

- introduction of homes for senior citizens within the scheme of transformation of post-industrial areas in the contemporary housing environment (example: Flintholm Care Home),
- introduction of homes for the elderly within the scheme of modernisation of housing estates from the 1960s (example: Bomi-Parken nursing home within the territory of the Gyldenrisparkensocial housing estate),
- introduction of homes for the elderly within the scheme of designing new urban districts (example: Ørestad nursing home on Amager island).

The first of the examples listed above – the Flintholm Care Home – is a home combining apartments for elderly people with secured access to services rendered by assistants. The two other examples are typical nursing homes.

Social building with apartments for elderly people in Flintholm, Frederiksberg. Arch. Frederiksen & Knudsen Architects, 2007

This example demonstrates the search for optimal mutual relations between inhabitants inside the complex. At the same time, it addresses their expectations in terms of strengthening their bonds with the local community.

Flintholm is located on the outskirts of Frederiksberg, which is an independent administrational unit situated inside the capital city of Denmark.

Location and relations with the surrounding area:

The decision about the location of housing structures for senior citizens is inscribed in the activities fostering the transformation of post-industrial areas into a contemporary district, with a rich urban programme. It is to serve different age groups, as well as to stimulate the development of the area and to generate new jobs. A new image for the district is to be created by the attractive housing and service complexes that are built here, such as schools, a cultural centre, day care centres for the elderly, retail outlets, and administrative and office facilities with high standards.

In this context, one must emphasise the dominating complex – thecomplex of theinternational auditing and consulting company KPMG (arch: 3XN, 2012) along with the new public space that accompanies it – Marguerite VibysPlads square, with a historic building of the gasometer and a green recreational zone. The programme of the area is completed with a sustainable energy-efficient building NCC'sFlintholm Company House with the BREEAM certificate (VilhelmLauritzenArchitects, 2011).

The building for senior citizens (FlintholmCare Home) is situated in the green urban interior that fills the quarter of multi-family housing development. The choice of the location for this building was connected with the need to secure close access to the main public transport routes, as well as to the new underground station – Flintholm Station (2004) –

for its residents. It is an important public transport hub, linkingthe area with the centre of Copenhagen, the underground lines, and the fast city train lines.

Architectural concept:

The social house with apartments for the elderly was erected according to a design selected in a competition. Thesmall scale of the facility was to give it an intimate, non-institutional character. It is designed on a floorplan in the shape of an ellipse, which enabled to inscribe it in the plot of land allocated to this development in a favourable way, and at the same time allowed to obtain larger, centrally positioned commonly utilised spaces intended for the residents' integration on each floor. These spaces house zones of activities and rest, kitchens, and dining rooms.

On the ground floor, there are the main entrance zone, administrative rooms, service outlets, and rooms for the staff. The other four floors house 50 independent residential units for elderly people, accessible from the commonly utilised interiors [2].

Il. 1–7. Flintholm Care Home: localization, architecture and its mixed-use neighbourhood.
Photo: M. Strzelecka-Seredyńska

A true advantage of this project is its location, which secures good access to all sorts of services in the close vicinity of the building, and the possibility of contacting other residents. This allows to strengthen the intergenerational solidarity and enhances the feeling of belonging to the neighbourhood. A feature that turned out to be disadvantageous for the house residents is the reduction of the size of the park that surrounds it compared to the one planned in the competition design.

Bomi-Parken nursing home in the Gyldenrisparken housing estate, Amager, Copenhagen, Denmark

Arch. WitrazArchitects, Vandkunstenand Wissenberg(authors of the revitalisation concept of the housing estate and of the design of the nursing home), 2006–2014.

This example presents a concept of inclusion of the housing development intended for senior citizens in the existing structure of the housing estate within the scheme of activities relating to its renovation.

The Gyldenrisparken social housing estate, erected in the 1960s (arch. S. Fournais and H.O. Christiansen, 1964–1966), is located in the Southern part of Copenhagen, on Amager island. It consists of 4-floor multi-family buildings, made of concrete pre-fabricated panels. Residents of the housing estate (900 people) are a diversified group in terms of family structure, as well as in terms of their ethnic and social background.

Sustainable revitalisation aimed to adjust the existing residential buildings and green areas to the contemporary standards. The concept of transformations stemmed from consultations with users, who were included in the designing process in compliance with the requirements pertaining to social housing in force in Denmark. The need to integrate and stimulate the local community inhabiting the housing estate was taken into account, by introducing a diversified programme of services, addressed to the youngest and the oldest residents. Within the scheme of the revitalisation measures, the quality of the green areas was improved as well by introducing new walking lanes, sports facilities, and playgrounds for children. The housing estate was furnished with elements of street furniture fulfilling practical and recreational functions. The leisure zones are adjusted to the needs of the residents of the nursing home.

As a result of the revitalisation, the living conditions of all people inhabiting the housing estate were improved. Additionally, favourable conditions for building bonds among neighbours were created, as well as for adjusting the living standards to the ones occurring in other districts of Copenhagen. Simultaneously, the attractiveness of the entire area was improved in functional and aesthetic terms.

Location of the nursing home, relations with the surrounding area:

The nursing home for senior citizens was introduced in the tissue of the revitalised housing estate, locating it in its central zone, in the common recreational zone, surrounded by the residential development subjected to revitalisation measures. The extended floor plan of the building is inscribed in the green interior designed with no barriers, accessible to all residents of the housing estate. The close vicinity of a modern, large, energy-efficient pre-schoolbuilding was intended to secure the inclusion of the elderly in the living environment of younger generations.

Architectural concept:

This two-floor building houses 81 individual apartments, adjusted to the needs of senior citizens, most of whom are aged 75 and above. The physical form of the structure has the shape of a ribbon enveloping the internal courtyards, which fulfil recreational functions. They are accessible to all residents of the housing estate.

The ground floor houses a programme addressed to its residents, as well as to the entire local community with the purpose of mutual integration. It comprises such services as an activity centre, spaces for different forms of movement therapy, a library, and a coffeeshop. Senior citizens also use service outlets located within the territory of the housing estate and in its close vicinity. Ecological solutions have been adopted in the building, such as e.g. a green roof and healthy construction materials.

The project discussed above constitutes a model solution, which combines revitalisation measures in the urban space with shaping of the living environment for the elderly, with no

Il. 8–14. Nursing home in the Gyldenrisparken housing estate: localization, architecture and its surroundings. Photo: M. Strzelecka-Seredyńska

barriers and exclusion. It is referred to as an example of a good practice in Denmark in terms of actions for the benefit of improving the standards of the urban space with the adjustment to the life cycle of different residents [8].

Ørestad nursing home, Ørestad, Amager, Copenhagen, Denmark
Arch. JJW Architekter, 2011–2012

This project isan example of inclusion of residential development for senior citizens in new, comprehensive urban complexes.

Ørestadis a district of Copenhagen at the edge of a natural reserve on AmagerIsland. The municipal plan from 1993 assumed that this area was to be transformed into a new, attractive urban space, located in the geographical centre of the Øresund region [1] Over the last decade this district has become a location of high-standard architectural projects, concentrating predominantly housing development and all sorts of services.

Location and its relations with the surrounding area:

The location of the residential building for senior citizens in the centre of the district aims to achieve its residents' integration with the surrounding area and to include them in the life of the city. The building is located in the Southern part of Ørestad, dominated by housing, in close vicinity to the Vestamager underground station. The building is inscribed in the quarter of urban development, situated at a recreational and walking route that accompanies a water canal. In close vicinity of the nursing home there is a housing complex for students (120 small residential units). Nearby there are also organised openareas for sports and recreation, cycling lanes, green areas, squares, and a pre-school.

Architectural concept

The architectural concept, selected in a competition, corresponds to the model of life proposed to the elderly and accepted by them in Scandinavian countries.

The complex consists of 114 residential units with balconies and terraces. It is designed around an internal courtyard, which is used for the purposes of common recreation. Its green interiors open up towards the residential buildings intended for students. A recreational function is also played by a garden located on the roof of the building.

The composition of the floor plan of the building, consisting of eight main units linked by means of passageways, corresponds to the development of housing estates composed along little streets and squares. Individual residential units for senior citizens, combined in complexes, are located near broad, bright spaces intended for shared activities and moving around. Interiors which fulfil the function of recreation can be freely shaped thanks to the application of sliding walls. The ground floor of the entire complex houses service outlets open to all residents of the district.

The attractiveness of this architectural solution is dictated by the shape of the building itself, its details in the form of balconies in characteristic, diversified shapes, as well as bright colours, which correspond to the colours of tenements located in the historical part of Copenhagen.

The project constitutes an example of implementing the principles of universal design in the everyday life of the elderly and their inclusion in the urban neighbourhood, diversified in terms of its programme.

Il. 15–19. Ørestad Nursing Home (Copenhagen): localization and architecture.
Photo: M. Strzelecka-Seredyńska

3. Summary and conclusions

The demographic situation in European countries, as well as the forecasts relating to it, means that architects and urban planners are facing a new challenge – the adjustment of the urban space to the needs of the constantly growing group of elderly and disabled people.

Based on the analysis of the latest solutions, it can be stated that in Denmark – similarly to other Western European countries – architects depart from designing residential projects for the elderly in the form of closed complexes, which only in the mid-20th century enjoyed great popularity. A tendency to search for an optimal inclusion of the living environment of senior citizens in local communities can be observed now. It is believed that providing senior citizens with appropriate housing standards and the opportunity to fully participate in the public life has a direct effect on their health and well-being.

The selected design concepts described above constitute answers to the expectations of most elderly people. They are recognised as examples of a good Danish practice in terms of actions for the benefit of improving the standards of the urban space, with the adjustment to the life cycle of different residents.

They share a similar approach to the selection of the location of the residential buildings within the city. Designing such facilities near green enclaves, in the vicinity of intensely developed areas, with good access to public transport, is definitely preferred.

The goal of such decisions is to create the conditions fostering active and creative participation of the elderly in the life of younger generations in the urban space with no barriers, exclusion, orfeeling of isolation. This approach is also consistent with the concept of designing a universal urban space adjusted to the needs of all generations (age-integrated society). It fulfils the expectations of the citizens of Denmark, too, who usually exhibit a strong community spirit, satisfaction with life, and social commitment. Elderly inhabitants of the country in particular constitute an open group of people who are willing to take part in different forms of urban life.

Combining the living environment of the elderly with other generations is also inscribed in the principles of sustainable urban planning, which promote combining different forms of services and housing development in order to obtain a cohesive, friendly, and attractive neighbourhood for young people, families with children, and elderly people (mixed-use neighbourhood).

To sum up, it should be emphasised that the quality of life of senior citizens in the city depends on the quality of the built environment as well as of the social environment. The quality of the physical environment is expressed most of all in decent housing standards, public space, as well as public transport. The social environment can, on the other hand, have a positive effect by stimulating active citizenship and professional activity, providing access to services, most of all medical ones, as well as activities fostering different forms of participation of senior citizens in the city life.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

ARCHITECTURE AND URBAN PLANNING

DOI: 10.4467/2353737XCT.17.170.7278

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On the creation of a social conceptual design of a public park – notes on a design employing the workshop method based on the case of Reduta Park in Krakow

O tworzeniu społecznej koncepcji parku publicznego – uwagi o projektowaniu metodą warsztatową na przykładzie parku Reduta w Krakowie

Abstract

The paper, in the form of a descriptive analysis, presents the method of designing a public park through the use of workshops. The structure of the entirety of the design, as well as important elements that a tutor – a specialist responsible for the animation of a group of members of the local community – should focus on, are presented in the work.

Keywords: city park, participation, a social conceptual design of a park, tutor, workshops

Streszczenie

Artykuł w formie analizy opisowej prezentuje metodę warsztatowego projektowania parku publicznego. Wskazano konstrukcję całości projektu oraz istotne elementy, na które powinien zwracać uwagę tutor – specjalista odpowiedzialny za animowanie grupy przedstawicieli społeczności lokalnej.

Słowa kluczowe: park miejski, partycypacja, społeczna koncepcja parku, tutor, warsztaty

1. Introduction

Increasing the level of knowledge and improving practical skills in the field of the cooperation between a specialist and non-specialist in the field of the shaping and design of public spaces is an element that is needed regardless of the ongoing scientific discussions on the subject of the validity of incorporating the idea of public participation into the practice of shaping public spaces. As cases of several locations in the world – with Poland included – have shown, the number of situations in which the local administration makes the decision to adopt a variant that allows residents to participate in making decisions regarding the image of the space in which they live, and which they use, increases. The various causes of this state of affairs and the arguments both for and against this type of participation of residents in decision-making aside, the analysis of projects that have already been carried out appears to be undoubtedly beneficial and valid. Pointing out both positive and negative elements of these processes allows us to draw appropriate conclusions and to perfect the methods and techniques that are employed to this end. This is why this work has the character of applied research, aimed at perfecting the professional toolkit of design in the field of the cooperation between professionals and non-professionals.

The goals of the work are:

- the presentation of a design structure that employs participation tools in the development of a conceptual design of a public space (a city park), (chapter 2),
- the performance of an analysis of the manner of cooperation between experts and persons who do not possess the factual knowledge and skills of architectural and landscape design and, by doing so, pointing to key elements of conducting work in a workshop group (chapter 3),
- pointing out the role and tasks of a specialist who animates a workshop group (chapter 3).

The method:

The work is based on the descriptive method with the use of techniques such as participatory observation and interviews, expanded through a study of the literature.

In terms of subject literature, the leading work is a two-volume publication under the editorship of Krystyna Pawłowska. Volume A [7, p. 172] is a source of knowledge that is more theoretical in nature, while volume B [8, p. 180] is a practical handbook dedicated to those who aim to implement the idea of public participation in order to protect and shape the landscape. Another fundamental work is the handbook under the editorship of Jerzy Hausner [6, p. 198]. It is one of the first works on the subject of the practical implementation of the participation of citizens in public life, but one that is directed more towards matters of public consultation than "active" participation that has been described as one of the upper levels of the "participation ladder" devised by Shery Arnestein [1, p. 216–224; 2, p. 12–39]. The subject of public participation is discussed in numerous works and this narrow choice does not block us from a wider range of publications, it is but a reference to works that broaden the subject matter [3, p. 26–44; 4, p. 312; 5, p. 181–188].

The work is composed of two main parts. The first is devoted to the description of the organisation and carrying out of the project, which had been devised as a participatory process with a structure based on design workshops, in which the local community was to take an active part. The second part consitutes a descriptive analysis of the cooperation of specialists educated in the field of architectural and urban, as well as architectural and landscape design, with a group of residents who are not experts in any field of design.

Current studies have shown that there is potential in the activity of local communities, which can be excellently put to use in order to create new positive values. At the same time, one needs to be aware of the dangers that the idea of participation entails, particularly that of manipulation [11, p. 183–195].

An increase in employing various forms of public participation in the process of making decisions regarding public matters has been observed for some time. These tendencies are also visible in Kraków. Some of the earliest experiences in this regard can be read about in the author's publications [12, p. 199–216].

Starting with the year 2014, we can increasingly often observe a strong focus on the voice of the public in matters regarding spatial development, especially that of public spaces and urban greenery, declared in public statements made by representatives of both the highest municipal authorities of Kraków as well as local administrative officials of various ranks, including members of the city council. The much publicised "Superścieżka" project, which has been implemented in 2015, was advertised as the first placemaking project in Krakow [13, p. 317–329]. Another project that has been carried out with the cooperation of the representatives of the municipality, non-government organisations, specialists, as well as residents and users, was the establishment of a public park in a zone that is intensely becoming denser with residential buildings, at the border of the districts of Prądnik Czerwony and Mistrzejowice.

2. Reduta Park in Krakow

The genesis of the entire project is based on a grass-roots initiative. The distrct's residents communicated the need to find a location for a park to their representative on the City Council. The idea has gained the acceptance of the members of the council, who passed the appropriate proclamation.

By doing so, they have established Reduta Park. This decision had a factual justification. The analysis of the area clearly indicated the need to for a public space with the formalised character of a city park to be created, one that would constitute a place of recreation and rest for a significant group of users. Although the nearby housing estates border on green areas located along the Sudół Dominikański creek (which can be treated as a wild linear park), due to its undeveloped character, it does not meet the requirements of a park accessible to a wide range of users. The wider area also includes Park Tysiąclecia, which stretches over an area of around 11 ha, in the district of Mistrzejowice (located a distance of around 1000 m in a straight line to the east of the Reduta park area). It was established in the 1970's as the recreational area for the residential estate of the same name that was being built at the same time. Nevertheless, both of the aforementioned urban open spaces do not provide an adequate area necessary for recreation in the wider area.

2.1. The Site

The fact that the entire area belongs to the municipality has been a highly comfortable situation from the point of view of managing the project. The area borders the Sudół Dominikański River from the north – which is one of the small rivers that criss-cross the area of Kraków. The river is surrounded by a belt of greenery with varying degrees of thickness, which is why it constitutes a natural ecological corridor and is a potential site for the establishment of a river park[1]. There is a relic of *architectura militaris* at the site, an Austrian military shelter that belonged to the system of the Kraków Fortress[2]. One characteristic quality of the area is its terrain: a delicate evening out from the south, a large slope in the northern direction and a delicate evening out further north near the creek.

Fig. 1. The site of the planned Reduta Park in the Prądnik Czerwony district of Krakow, with its immediate urban surroundings. The park's surroundings are composed of high intensity developments and areas assigned for these types of developments. Source: Original work based on an orthophotomap from www.googlemaps.com

Fig. 2. Plot of the future Park Reduta. Source: author's photo

1 The idea of "River parks" proposed by Aleksander Böhm, despite being included in the regulations of the SDCaDS of Kraków did not take on visible form. This situation is slowly changing. Both the municipal administration and the residents have come to see the potential of the areas along Krakow's waterways.

2 The nearby street and the newly designed park are named after it – Redute (Redoubt in Polish – transl. note).

The area is surrounded by intense residential developments from the 1990's and the 2000's, as well as very recent multi-family residential structures which are being built simultaneously with the park. The estimated amount of residents that will constitute the potential users of the park oscillates around 20 000. It includes the current residents of the surrounding housing estates, as well as the future residents of the residential complexes that are under construction.

2.2. The Idea

After the establishment of the new park by the means of a proclamation by the city council, a decision has been made under the influence of growing interest in public participation, regarding the implementation of this idea in the development of the park's conceptual design. However, before the workshop took place, the directions in which the workshop groups were to operate towards were established. These directions were outlined by the term: park of the cultures of the region, as well as by three thematic fields: nature, architecture, culture. The name pointed in the direction of thinking of the future park as a place where one would be able to experience the cultures of the region, both in the classical sense (experiencing the cultures of the region on a wider scale, without the necessity of travelling outside the city), but also in the sense of „very" local culture, that which would be created by this place and its uers. The three terms: nature, architecture and culture pointed to the necessity of making the new park stand out from traditional ones by giving it an educationl function, featuring an offer of a broad programme of workshops, meetings and activities that would encourage the residents to be active. The outlined direction provided the general framework for the ideas of which this vision was to be composed of. This, in turn, became the foundation for the development of a detailed conceptual design of the park – this time on the designer's „drawing board".

2.3. The structure of the project – a synthesis

Five basic stages can be pointed to within the structure of the project:

1. Preparation, 2. Participatory workshop, 3. A presentation of the designs and a vote (selection), 4. The development of design documentation. 5. Construction.

Ad. 1. The stage of preparations is crucial and a lot depends on it. This period was devoted to the development of a plan of action among experts. The main programme of the project and functional and programmatic directions were developed as well. The list of specialists, tutors and all those involved on the side that organised the project was closed. It is very important to identify stakeholders and find a channel through which they can be reached. After the work on the plan and the making of technical decisions had been finished, an information campaign was carried out, which had a continuous character and made use of both traditional and social media. The so-called „word of mouth" – informal channels of reaching the target audience through acquaintances, neighbours and their contacts – was also of significant importance.

Ad. 2. Design workshop – the key and most intensive stage. Despite making premade plans, it can develop in unforeseen directions. It is expected to be a form of gathering the fullest amount of information on the site and kickstart creative thinking in search of ideas for the main concept, around which the conceptual design of a park can be built. Each of the workshop meetings began with a starting presentation, showing good examples or elements that would otherwise stimulate work. In this case, the interested participants were divided into six work groups, supported by two tutors. Each of the groups developed its own proposal. The role of tutors is immensely important. They are members of a group and can file their own proposals and ideas, but at the same time must enforce the rules of cooperation, animate the activity of the group members and, should the need arise, ease any tensions or distribute tasks. They are also the „hands" of a group – they draw, visualise and help in the preparation of presentations. The difficulty of their task is based on the simultaneous fulfilling of multiple roles.

Ad. 3. The presentation of the works in a concise form; easily accessible and equitably presenting each of the propositions. In the case that is being discussed, traditional architectural visualisations were abandoned in favour of textual descriptions and schemes in the form of map drawings, with the latter being enriched by reference images. The abandonment of the use of visualisations was to avoid voting for „pictures" – the elimination of the factor dependent on the preferences in taste regarding the form of elements and focusing on the basic objectives of the functioning of the park and its functional and spatial programme. The voting was performed in the form of an Internet-based opinion poll. The conclusion of the vote ended with a public exhibition of the results with an original presentation of the winning proposal.

Ad. 4. The vision of the park that had been selected through the voting process became the basis for the development of a detailed conceptual design, prepared by a professional design team. Afterwards, the conceptual design was publically presented, which provided an opportunity to gather additional feedback and opinions. The administrative process, during which technical documentation is developed and all formalities associated with obtaining a construction permit are taken care of, begins after the aforementioned elements are implemented.

Ad. 5. The construction of the park and its furnishing begins after obtaining a construction permit.

It is crucial that an information campaign be conducted in parallel to all the stages of the project, providing constant access to up-to-date news on the state of the work.

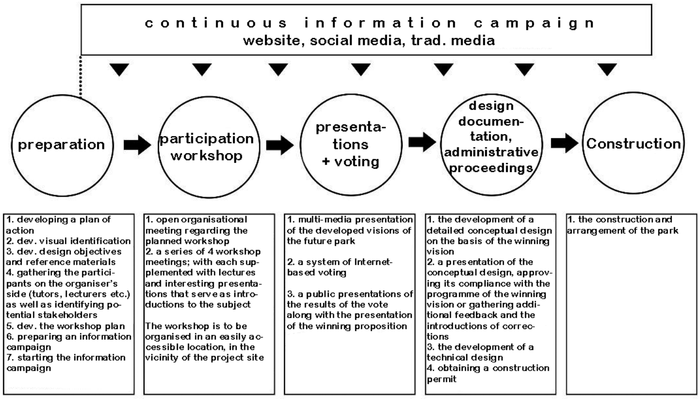

Fig. 3. A scheme of the structure of the participation project. Source: original work

3. Experiences

The advantages of the workshop method have been described in the publication under the editorship of Krystyna Pawłowska [8, p. 96–101], which also includes examples of how workshops can be conducted. The example that is discussed here differs from the one presented in the aforementioned work. The main difference is the division into workshop groups that work on the same theme, the vision of the entire park, instead of developing separate fragments of the whole park by each team. The element of competition between groups who wanted the vision developed by their members to be selected in the Internet poll was introduced (not in a completely deliberate manner, but rather as a result of the convention of conducting the work). This rivalry resulted in a positive effect in the form of the involvement of group members in the performing of tasks and driving the members to strive to develop the principles of the functioning of the park that was being designed in the best possible manner. Additional elements that were to inspire increased interest and convince others of the superiority of the vision that was being presented over the other ones were also added to the presentations of all participants on the workshop forum. The presentations were also enhanced by assigning specific roles to group members, providing musical illustration or elements of choreography.

Every designer that deals with working with groups of people who are not professionally involved in design work must be aware of certain situations that can arise during this type of work. The most improtant of these have been presented below. In addition, ways of reacting to them and means of solving difficult situations have been provided.

3.1. Breaking the ice

Beginnings always pose a certain problem. The circumastances of a new environment, a new situation, unknown people and the necessity of working with them can lead to awkwardness and embarrassment. It is the role of the tutors to establish a friendly atmosphere that is conducive to discussion and creative work. It is good when tutors start with introducing themselves both from the professional side, as well as the more private one. On the one hand, this builds an image of a competent and professional person, and on the other reduces barriers and shows the more „human" side of the specialist. The tutors should encourage the rest of the group to perform similar introductions, so that all the participants can get to know the rest of the group and get the opportunity to make their voice heard. A less formal and looser atmosphere is better for good cooperation.

3.2. Different goals and views among participants

A group can consist of persons with completely different views and ideas or it can include a tightly knit group of persons who know each other and that can attempt to use „lobbying" to enforce a previously decided-upon version. We can attempt to avoid the second situation during the registration of the participants, separating groups, families, etc., assigning their members to different work groups. In the event that a group contains persons with completely different views or visions and who voice them from the start trying to impose their own point of view on others, they needs to be reminded that the group has convened in order to achieve a specific goal: develop a common vision, and that there is a specified amount of time for it to be done. It is also good to present the rules of cooperation right at the start, describing the role played by the tutors within the group and reminding of the most important conditions that should be taken into account from the point of view of professionals. This last task should be directly combined with a request to present individual (from the point of view of a user, a resident of the area, and thus a person „in the know") observations and conclusions on local conditions. This can be the first common task – making everyone participate in it, while also constituting an opportunity to update starting information on the site, its needs and potential. In the case that is being discussed, one of the participants had brought their own vision of the park drawn on paper to the first workshop meeting and proclaimed that the future park should look like this. By implementing the technique described above, the participant was convinced that the goal of the workshop is the development of a common conceptual design. In addition, the participant was assured that the concept the participant had delivered could always serve as a „last chance" drawing, to be used in the event that the entire group would not think of anything else.

Fig. 4. A drawing depicting a conceptual design of the arrangement of the park that was brought by one of the workshop's participants as a plan ready for implementation. Source: Original work

3.3. Stimulating non-stereotypical thinking

One of the basic arguments employed by opponents of public participation is the observation – which is, nevertheless, often confirmed by reality – that residents often have stereotypical ideas for the design of a park and simply propose the adding of benches, litter bins and lighting. One of the basic and at the same time important tasks of the tutors is to work out a need for the inhabitants to view the park as a pretext for deeper intellectual pursuits. During work on this case, the tutors devoted the entirety of the pre-workshop meeting to implant the need to build an idea for the park instead of only deciding on the layout of the paths and the placement of each element. The tutors, by providing interesting examples (using images from the Internet, as well as their own experiences) convinced the group to search for cultural and historical references, which resulted in the issuing of homework to the participants and the preparation of valuable materials, from which „key content" was picked afterwards. Thus, by referring to historical figures living in the area (famous painters) a concept of a „painting" park was developed, featuring picturesque frames bringing to mind association with the work of Polish painters from the turn of the centuries.

3.4. Making the goal a common one

The simultaneous presence of different expectations among participants regarding the site is an important problem that nearly always occurs during such projects. In this situation, one needs to remind the participants about the goal that is to be achieved during the workshop. It is a common vision of a park, one which needs to be worked on together. In the event of a very intense conflict in a group, it is often good to use the technique of „defending the opponent's position". It is based on asking the most active participants, who defend their positions most vigorously, to find arguments that support the position of the opposing side. This may not necessarily lead to a sudden change of opinion, but it will send out a strong signal that others also have their needs and come here with similar demands. It can also help in searching for, if not compromise, then „third" solutions at least.

3.5. Silence and shyness, as well as chaotic exchange of ideas

One situation that is often encountered, especially at the start of working in a group, is the difficulty in initiating work and the exchange of ideas. There are many ways of encouraging people to work. However, there is a lot that depends on the tutors who animate a group. Their duty in this situation is to find a point from which to start, a sort of common ground with the members and to stimulate their activity. It is often good to recall one's own memories with an area (or, in the case when the tutor has nothing in common with the site, memories of a similar place should be recalled).

A loose formula of cooperation and conducting the workshop in an attractive manner can lead to the free expression of ideas and observations by the participants. On the one hand, this is a desired situation, as every loose thought and seemingly irrational idea can, under the influence of group work, be turned into a valuable concept. On the other hand, it introduces chaos and disorder into work. This problem can be solved by making a plan of action and setting intermediate goals. Apart from this, the authors should vigilantly identify and write down „potential ideas" which can prove to be priceless in the future.

3.6. A hyperactive participant

Sometimes, a group can include a person that very strongly focuses the attention of others on their ideas or a person that occupies most of the time with secondary matters. Should attempting to convince such a person that a group is to work on a common conceptual design fail to work, two approaches can be used. In the first, one of the tutors „ties down" the hyperactive participant, by listening to them, meticulously writing down their demands and commenting on them, etc. This allows all the topics brought up by this participant to be exhausted. This should be done in a manner that does not disturb the rest of the group, which can perform work with the other, less-burdened tutor. The second approach is to give the hyperactive participant a specific task, for instance the writing down of their demands in the form of points and for them to propose the means of achieving them. Specific, personally dedicated tasks are also a good method of keeping hyperactive or „disruptive" participants under control.

3.7. Homework – fostering a group's engagement

Workshop meetings are a time of very intense work. Sometimes it may happen that they do not provide enough time to reflect on an issue and perform its in-depth analysis. It is good when tutors manage to encourage the residents to work at home (finding something, talking about a problem with other residents, finding attractive solutions from other areas, etc. It is also an occasion to encourage the residents to invite their families, neighbours and acquaintances to work with them. Homework can provide a good context for fluidly starting another workshop meeting: the work performed at home can be presented after the previous meeting had been summarised.

Fig. 5. A presentation drawing of featuring the programme developed by Group 2. Tutors: Marcin Nowicki, Miłosz Zieliński. Prepared in the form of a map with a scheme describing spatial and programmatic dispositions. Source: Original work

4. Summary and conclusion

In the case that is being discussed, the groups developed their own visions, which were then subjected to a public vote. The question whether this is a better formula than developing a single, common concept of a future park can be considered valid. In essence, both formulas are good – they lead to the achievement of a goal, that goal being the activation of the residents, gaining valuable information, „allies" in successive stages of work, etc. The second option of conducting workshops is better suited for spaces that have a smaller scale, in the case of which the group of users is limited and will make use of the mutually developed conceptual design. The introduction of the element of competition is sensible especially in the case of larger projects (e.g. of a district-wide scope). The benefit of this approach is the natural desire to win in a competition, which in this case is being directed at the development of a vision of the park that the majority will be pleased with. This stimulates people to work harder and be more creative. The second advantage is that the circle of stakeholders expands. Thus, the workshop's participants become „active" participants of a project, while the larger group of people who vote in the selection of a conceptual design also participate, but more „passively". Another advantage of this form of workshops is illustrated by an opinion of one of its active participants, whose conceptual design came second in the vote. She pointed out that, apart from the obvious disappointment (everyone wants the conceptual design of their group to be implemented) she was happy with the conclusion and could not wait for the park to become open for use. This is evidence of the value that the workshop method has for society.

The analysis of the approach to designing a city park with the use of public participation based on the workshop method that has been presented in this article points to the improtant role that tutors – who are most often educated designers of architecture, urban planning and landscape architecture – play during similar endeavours. The role that they play during workshops is not limited to simply „drawing" – providing an image of the effects of the common work of an entire group. The activity and creativity of the workshop's participants depends on their involvement and skills. Thus, we are led to the conclusion that, as the popularity of this method increases, we should ensure that specialists receive the proper theoretical and practical preparation for work with a group of „non-specialists" – reinforcing the competencies of specialists in this field.

We should also not forget about the weaknesses of this method. The lengthening of the entire process can be considered one of them. Even when all the stages are shortened to the minimum, workshops require time. Particular attention during the organisation of such projects should be paid to the manner of public voting in order to eliminate potential charges of vote manipulation, etc.

It would also be beneficial to ensure that the subsequent stages of a project (the conceptual design stage, construction, etc.) can be monitored by stakeholders.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

CHEMISTRY

DOI: 10.4467/2353737XCT.17.177.7285

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Investigation of temperature distribution in the ground induced by heat source and under natural conditions

Badania rozkładu temperatury w gruncie wywołanego źródłem ciepła oraz w warunkach naturalnych

Abstract

This paper deals with theoretical and experimental analysis of heat transfer in the ground. Calculation results of heat transfer under natural conditions were presented. Temperature profiles in the ground were determined for cyclic steady state. Results of experimental studies conducted in laboratory setup were shown. Experimental studies were related to determination of temperature of the heated granular bed. The calculation and measurement results presented were used to determine a mathematical model of the ground heat exchanger.

Keywords: process modelling, transient heat conduction, renewable energy sources

Streszczenie

Artykuł dotyczy analizy teoretyczno-doświadczalnej przenoszenia ciepła w gruncie. Przedstawiono wyniki obliczeń przenoszenia ciepła w warunkach naturalnych. Wyznaczono profile temperatur w gruncie w zależności od czasu dla cyklicznego stanu ustalonego. W części eksperymentalnej przedstawiono wyniki badań prowadzonych w instalacji laboratoryjnej. Badania dotyczyły wyznaczenia temperatur w ogrzewanym złożu ziarnistym. Przedstawione wyniki badań i obliczeń zostały wykorzystane do opracowania modelu matematycznego gruntowego wymiennika ciepła.

Słowa kluczowe: modelowanie procesów, nieustalone przewodzenie ciepła, odnawialne źródła energii

Nomenclature

a – thermal diffusivity of the ground, m^2/s
B – oscillation amplitude around the temperature T_b, K
Bi – Biot number
C_1, C_2 – constants dependent on the Biot number
c – heat capacity of the ground, J/(kgK)
h_0 – heat transfer coefficient, $W/(m^2K)$
k – thermal conductivity of the ground, W/(mK)
L – damping depth, m
q_v – rate of heat generation per unit of volume, W/m^3
t – time, days
t_c – cycle time, days
t_{max} – time from the beginning of the year until the maximum ambient temperature is reached, days
T – temperature, °C
T_a – ambient air temperature, °C
T_b – temperature of the ground at great depth, °C
T_0 – temperature of the ground surface, °C
x – position coordinate, m
ρ – ground density, kg/m^3
ω – frequency, 1/s.

1. Introduction

The ground is an advantageous heat source for heat pumps. In comparison with the air it has a much more stable temperature and a high specific heat.

Ground heat exchangers are essential parts of ground-source heat pumps. The ground heat exchanger is used for extraction or injection of heat from/into the ground by a heat transfer fluid which circulates in a closed cycle. There are two types of ground heat exchangers, namely horizontal and vertical systems can be used. Horizontal ground heat exchangers have a significant advantage over vertical ones. In the former, shallow layers of the ground are being cooled as a result of extraction of heat from the ground by the exchanger; these layers are in a direct contact with the environment. This results in the fact that the cold ground takes more heat from the environment during the warm period of the year and loses less heat during the cold period. Vertical exchangers do not have this beneficial feature as the cold ground at a great depth is not able to compensate the heat loss by receiving heat from the environment [1].

Horizontal ground heat exchangers have been widely used in many countries as a heat source for ground-source heat pump systems. Therefore, ground heat exchangers are the subject of many studies that are both experimental and numerical. For example Wu et. al. [2, 3] investigated the thermal performance of slinky heat exchangers for ground source heat pump systems for the UK climate. The authors presented the results of experimental measurements as well as of numerical simulation.

In order to estimate the power gain while using a heat pump coupled with the ground heat exchanger one should analyse the temperature distribution in the ground under natural conditions.

The aim of this work is to provide important data for a ground heat exchanger design, which is temperature distribution in the ground. The temperature field was determined numerically and experimentally. In this research paper the elements of modelling of heat transfer in the ground as well as measurement results of heating process of the granular bed in laboratory setup were presented. Both aspects play an essential role in developing the mathematical model of a ground heat exchanger coupled with a heat pump.

2. Analysis of temperature distribution in the ground under natural conditions

It was assumed that conduction is the only mechanism of heat transfer in the ground, coefficient of thermal diffusivity is invariable over time and space as well as heat transfer taking place only in the direction of the *x*-axis (vertical). The equation of heat conduction has the form:

$$\frac{\partial T}{\partial t} = a\frac{\partial^2 T}{\partial x^2} + \frac{q_v}{c\rho} \tag{1}$$

Under natural conditions due to no heat exchanger installed the rate of heat generation $q_v = 0$. The boundary condition for the surface of the ground is as follows:

$$x = 0 \quad -k\frac{\partial T}{dx} = h_0\left(T_0 - T_a\right) \tag{2}$$

In the above relationship the quantity h_0 is the apparent coefficient of heat transfer between the ground surface and the environment. This coefficient determines heat transfer by both: convection and radiation. Due to changes in thermal conditions on the surface of the ground, the quantity h_0 is averaged over time.

The ambient temperature T_a changes periodically according to the relationship:

$$T_a = T_b + B\cdot\cos\left[\omega\left(t - t_{\max}\right)\right] \tag{3}$$

where the cycle time $t_c \approx 365$ days, hence the frequency $\omega = 2\pi/t_c = 0.0172$ day^{-1}. On the basis on the data for Kraków, shown in [4], constants in relationship (3) were determined. These constants are as follows: $T_b = 8.5°C$, $B = 10.4$ K, $t_{\max} = 198$ days.

The ground should be considered as a semi-infinite body. Hence, the second boundary condition related to a constant temperature of the ground at great depth has the following form:

$$x \to \infty \qquad T = T_b \tag{4}$$

The solution of equation (1) with boundary conditions (2–3) and (4) leads to the relationship for the cyclic steady state [5]:

$$T = T_b + BC_1 \cdot \exp\left(-\frac{x}{L}\right) \cdot \cos\left[\omega\left(t - t_{\max}\right) - \frac{x}{L} - C_2\right] \tag{5}$$

The constants C_1 and C_2 are dependent on the Biot number:

$$C_1 = \frac{Bi}{\sqrt{(Bi+1)^2 + 1}} \tag{6}$$

$$C_2 = \tan^{-1}\left(\frac{1}{Bi+1}\right) \tag{7}$$

where *Bi* is the Biot number determining the ratio between the internal and external thermal resistance to heat transfer:

$$Bi = \frac{h_0 L}{k} \tag{8}$$

The internal resistance to heat transfer is located in the ground, while the external one is related to heat transfer between the ground surface and the atmospheric air.

If the external thermal resistance is slight in comparison with the internal one, $Bi \to \infty$ and then $C_1 = 1$, $C_2 = 0$. In this case relationship (5) simplifies to the form [6]:

$$T = T_b + B \cdot \exp\left(-\frac{x}{L}\right) \cdot \cos\left[\omega\left(t - t_{\max}\right) - \frac{x}{L}\right] \tag{9}$$

In definitions of *Bi* the quantity *L* is a damping depth defined as follows:

$$L = \sqrt{\frac{2a}{\omega}} \tag{10}$$

In Figs. 1a and b the temperature profiles in the ground, determined according to relationships (5) and (9) are presented. The ground temperature profiles are shown for 1.5-month intervals. The calculations were performed for $Bi = 2$ and $Bi \to \infty$. As one can see from Figs. 1a and b, for $x/L > 5$ the temperatures change slightly. In addition, for smaller values of *Bi* the temporal variations of temperatures in the sub-surface layers of the ground are insignificant. For example for $a = 0.5 \cdot 10^{-6}$ m^2/s the damping depth $L = 2.24$ m was calculated. For this value stabilization of the ground temperature takes place at a depth below around $5 \cdot 2.24 \approx 11$ m.

In Table 1 the calculation results of temperature of the ground for different dates for finite ($Bi = 2$) and infinite values of the Biot number are presented. In this second case because of the lack of the external thermal resistance to heat transfer, temperature of the ground is identical with ambient air temperature. The numbers in the 4th and 5th columns correspond to values read from Fig. 1b for $x/L = 0$. In the last two columns the values of the ground surface temperature corresponding to $Bi = 2$ and $Bi \to \infty$, respectively, are shown. The values of the temperature for $Bi = 2$ should be treated as more realistic in comparison with the values calculated for $Bi \to \infty$. Differences in the temperatures from the last two columns show that the conditions on the ground surface substantially affect its temperature and consequently the amount of heat which the ground can receive from (or transfer to) the air.

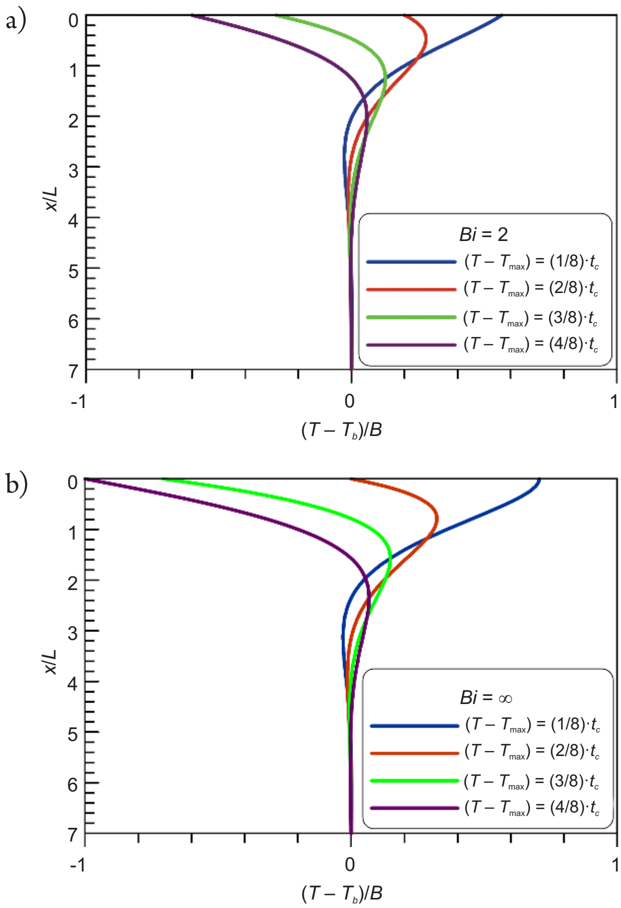

Fig. 1. Ground temperature profiles for a) $Bi = 2$, b) $Bi \to \infty$

Table 1. Temperatures of the ground surface

$(t - t_{max})/t_c$	t [days]	date	$(T - T_b)/B$		T [°C]	
			$Bi = 2$	$Bi \to \infty$	$Bi = 2$	$Bi \to \infty$
1/8	244	Sep 1	0.565	0.707	14.4	15.8
2/8	289	Oct 15	0.200	0.000	10.6	8.5
3/8	335	Dec 1	–0.282	–0.707	5.6	1.2
4/8	380	Jan 15	–0.597	–1.000	2.3	–1.9

The difference between the ground temperature T at specified depth and temperature of the ground surface $T_0 = (T)_{x=0}$ was also analysed. Dependence between the difference $T - T_0$ with the position for individual, considered days in a year was presented in Fig. 2. The greatest value of differences, above 10 K, falls into periods of the lowest and the highest ambient temperature. These maximum differences are reached at a fairly large depth (approx. 5 m). During transitional periods (Apr 15, Oct 15) temperature differences between the interior of the ground and its surface are slight. Maximum values, about 3 K, are reached at depth approx. 2 m.

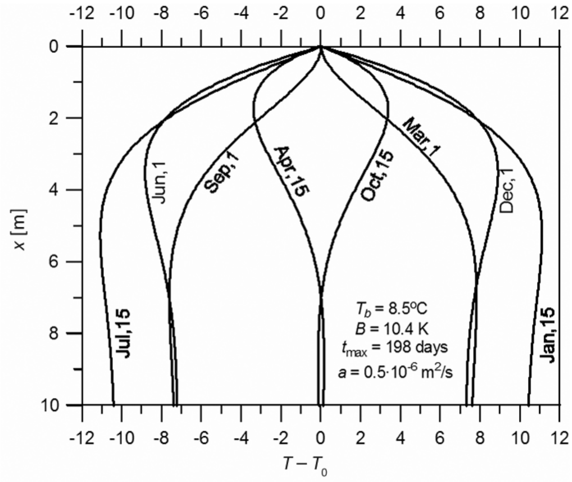

Fig. 2. Dependence of the difference of temperatures $T - T_0$ on position and time

3. Experimental investigations of heat conduction in a granular bed

When a heat exchanger is installed in the ground the rate of heat generation per unit volume q_v does not equal zero, which results in changes in temperature distribution in the ground in comparison with natural conditions. In this case the heat source constitutes heat exchanger tubes located horizontally at a specified depth.

In papers [7, 8] numerical simulations of heat conduction in the ground with an arrangement of horizontal and parallel heat exchanger pipes in it were carried out using the ANSYS application. The experimental investigations described below were carried out in order to verify obtained numerical results and to examine the temperature profiles in the ground.

Experimental studies concerning the temperature distribution in granular bed were performed in a laboratory setup, which was composed of two horizontal copper pipes 10 mm in diameter placed in a grain material – dry quartz sand [7]. The distance between the pipes was equal to 300 mm. The heat transfer took place in a 650×450×150 mm organic glass cuboidal vessel. Copper pipes for almost the entire length were lagged. There was no insulation only at sections located horizontally in vessel (with 150 mm length). The scheme of this experimental setup is shown in Fig. 3.

Water at a temperature of 50°C was flowing through the pipes. Appropriately a high flow rate of water provided a practically temperature invariability between the inlet and the outlet of the vessel. The initial sand temperature was equal to 21°C. The temperature outside of the vessel with the granular bed was also 21°C.

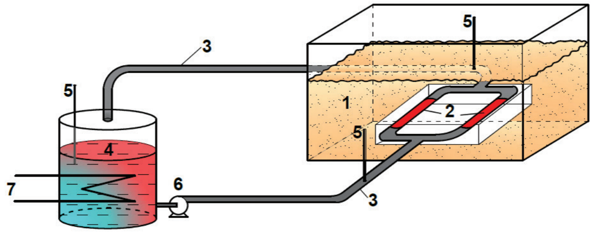

Fig. 3. Scheme of experimental setup (1 – vessel with granular bed, 2 – pipes without isolation, 3 – lagged pipes, 4 – thermostatic tank, 5 – thermometers, 6 – pump, 7 – heating element)

24 temperature sensors DS18B20 (± 0,5°C) were placed round the pipes according to the scheme in Fig. 4. The sensors were connected with a data processing system (Lämpömittari). The duration of measurement was equal to 10 hrs.

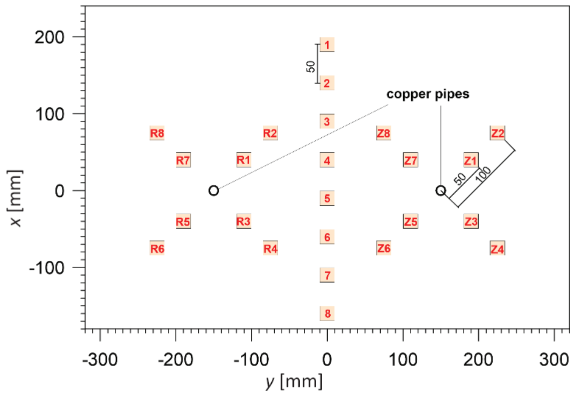

Fig. 4. Scheme of temperature sensor locations

In Fig. 5 the temperature variations of individual sensors were shown. Red indicates the courses designated by the sensors located closest the pipes (50 mm), blue – by the sensors located at a distance of 100 mm from the tube, and brown – by the sensors arranged vertically in the middle of the vessel between the tubes (as presented in Fig. 4). The highest temperature (29–30°C) were registered by sensors placed in close proximity to the pipe. Sensors located around the pipe, but at a greater distance, recorded a lower temperature – an average of about 3°C. The lowest temperature were recorded by sensors located between the pipes.

In Fig. 6 experimental maps of isotherms in granular bed for different heating process duration time were shown. The figures are related to the cross section of the system of pipes. The lines of constant temperature of the bed expressed as number (in °C) were presented. The axes correspond to the respective coordinate positions within the container.

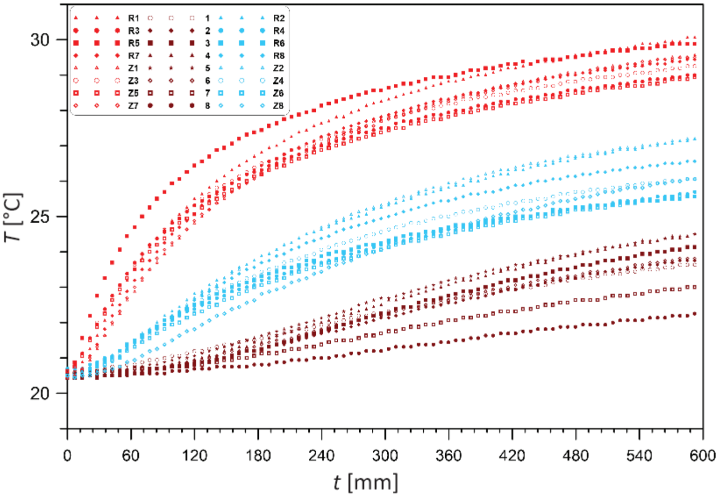

Fig. 5. Measured temporal courses of temperature of granular bed

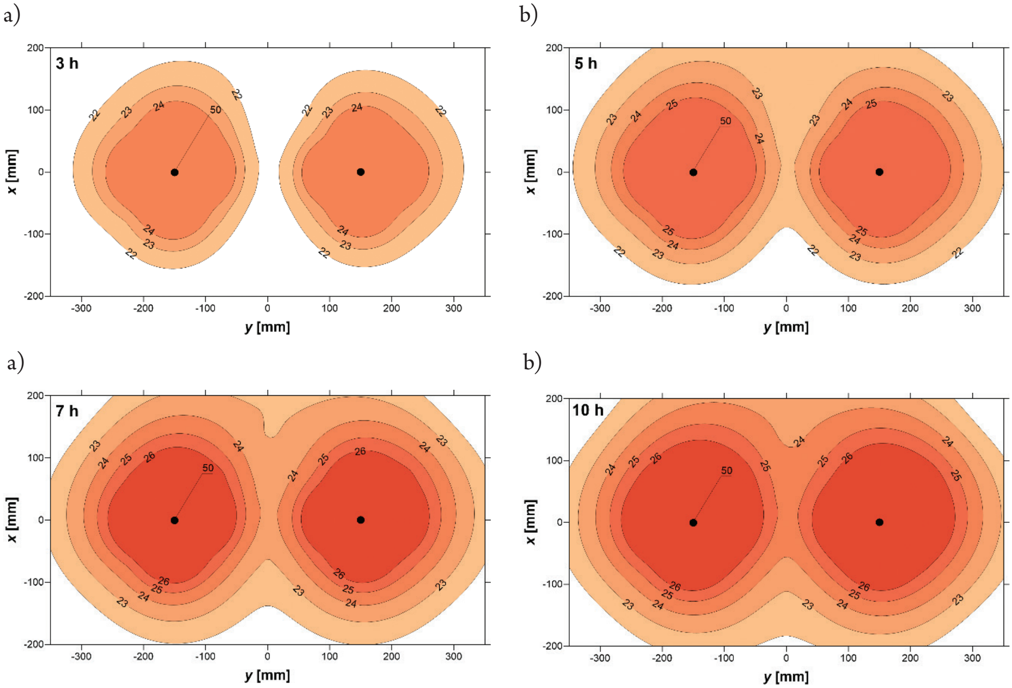

Fig. 6. Experimental maps of temperatures for a) 3 h, b) 5 h, c) 7 h, d) 10 h of heating process of granular bed

As you can see, at the beginning (3 h) each pipe heats the ground individually, independently of the other pipes. The isotherm shapes approximate a circle. However, after some time, the temperature fronts come together and their shape is flattened. After 5 hours of heating process the isotherms of 22°C are linked, isotherms of 23°C are connected after 7 hours and isotherms of 24°C – after 10 hours.

4. Conclusions

The resistance to heat transfer between the surface of the ground and the environment (external thermal resistance to heat transfer) strongly affects the temperature distribution of the sub-surface layer of the ground.

Performed experimental results confirmed the numerical simulations [7, 8] – at the beginning each pipe heats the ground individually and after some time the temperature fronts come together and an increasing part of lines of constant temperature has more rectilinear and parallel to the horizontal position. Thus, the system behaves similarly to the heating the ground by infinite plate. The similarity is even larger when there are more pipes installed and the more densely they are arranged side by side. That provides the basis for utilizing the one-dimensional equations of heat conduction for modelling of horizontal ground heat exchangers.

On the base of analysis of received courses of temperature isolines in the ground a simplified mathematical model of heat transfer in a horizontal ground exchanger has been worked out and verified with experimental measurements [9].

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

CIVIL ENGINEERING

DOI: 10.4467/2353737XCT.17.172.7280

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Production engineering tools for civil engineering practice – the case of QFD

Narzędzia inżynierii produkcji w budownictwie – przypadek QFD

Abstract

This article is a part of a series of papers which discuss the usefulness of production engineering tools for general civil engineering. Applications of selected production engineering tools in civil engineering are presented in these papers. The diverse nature of the tools is considered while outlining detailed areas of their application in civil engineering. The features of the tools make them representative of production engineering methodology. Thus, information about the civil engineering applications of the tools also makes it possible to draw practical conclusions about the general usefulness of production engineering methodology in civil engineering. The applications of quality function deployment (QFD) are utilised in this regard in the article.

Keywords: civil engineering, construction, decision, support, production engineering, tool, application, QFD

Streszczenie

Artykuł stanowi część cyklu prac poświęconych użyteczności narzędzi inżynierii produkcji w szeroko pojmowanym budownictwie. Uwzględniając zróżnicowany charakter wybranych narzędzi inżynierii produkcji, przedstawiono w cyklu szczegółowe obszary ich zastosowań w budownictwie. Cechy wybranych narzędzi sprawiają, że dobrze ilustrują one metodykę inżynierii produkcji. Dlatego na podstawie informacji dotyczących ich zastosowań w budownictwie, można sformułować praktyczne wnioski dotyczące przydatności metod inżynierii produkcji w budownictwie. W artykule wykorzystano w tym celu narzędzie narzędzie QFD (*quality function deployment*).

Słowa kluczowe: budownictwo, decyzja, wspomaganie, inżynieria produkcji, narzędzie, zastosowanie, QFD

1. Introduction

The present article illustrates the usefulness of production engineering (PE) tools using examples of quality function deployment (QFD) applications, instead. The paper is structured as follows: QFD is described in section 2; section 3 deals with civil applications of the tool; the usefulness of the tool is concluded in the final section.

2. QFD

The QFD tool facilitates meeting customer needs while preparing products, services and processes. The needs are expressed by the so-called voice of customer (VoC) which is defined by a set of customer requirements (CRs). The tool allows the translation of the VoC into a set of technical requirements (TRs) which are utilised by a producer, a service provider or a process performer to describe the provided product, service or process, respectively. CRs are translated into TRs thanks to the application of a house of quality (HoQ) diagram (Fig. 1) which expresses relationships between both groups of requirements.

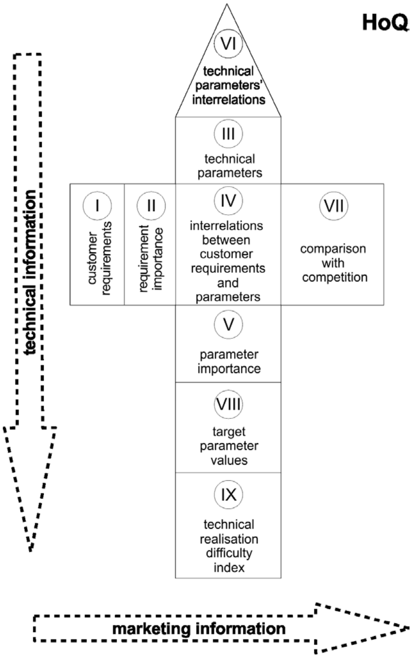

Fig. 1. HoQ application

Analysis of the Scopus bibliographic database contents reveals that there are over fifty database records which deal with the application of the tool in civil engineering. QFD has undergone some modifications for the purpose of enhancement; it also enhances other tools by means of mutual support. Standalone QFD tool applications nevertheless seem capable of providing sufficient means for the illustration of the potential of the tool in civil engineering.

3. QFD applications in civil engineering

QFD is utilised in civil engineering in five distinct areas. Design support makes the first application area. The following goals are considered in this regard:

- preparing structural engineering design models for organisation analysis [1];
- shaping low-cost building design solutions while raising quality and speeding up construction [2], improving building design reliability and quality while meeting the needs of diverse stakeholder groups [3], assessing of usefulness of material and

constructional solutions while limiting potential changes in construction [4], and supporting the integrated redesigning of dwellings for families with disabled persons [5];
- defining expectations and profiles of high building users [6], identifying key satisfaction factors for owners of ultra-modern villas [7] and roles played by stakeholders who are involved in sustainable choice of thermal insulation solutions [8];
- defining requirements relating to public buildings [9] and functional requirements towards wooden sound insulation plates [10], the identification of key factors for environmental-friendly hospital design while taking into account the needs of potential users [11];
- preparing and implementing a knowledge-based system for supporting the assessment and the choice of material and structural design solutions for high building elevations [12, 13], preparing a software tool for the multi-goal optimisation of design solutions to facilitate the implementation of office building thermal modernisation policy [14];
- design of an intelligent decision support system for safety management in construction [15].

Within the field of civil engineering, QFD is also applied in the area of planning the implementation of construction projects. The following example goals may be considered in this regard:

- comprehensive consideration of investor needs while preparing the implementation of a construction project [16] as well as comprehensive assessment [17] and prequalification [18] of potential contractors;
- defining public preferences with regard to projects concerning infrastructure [19];
- the consideration of the explicit and implicit needs of users of the building hardware [20].

The third QFD application area is devoted to construction project implementation assessment. For example, the tool may be applied to validate the compatibility of project implementation effects with investors' design, constructional, occupational, and maintenance requirements [21].

The assessment of a construction enterprise and effects of its performance constitutes the fourth QFD application area in civil engineering. The tool may be applied to assess:

- quality of constructor services in the case of a design/build construction project [22, 23];
- design/build enterprise effectiveness [24];
- human resources of a construction enterprise *see above note* [25].

The fifth QFD application area in civil engineering may deal with the following general goals:

- the identification of key factors for making design/build enterprise staff [26] and circle of professionals (architects and building engineers) [27] interested in the application of QFD as well as outlining a rational QFD implementation procedure [28];
- defining level for data visualisation which is necessary for improving the effectiveness of communication in civil engineering [29];
- facilitating the transformation of a competition-driven building market to a quality-driven building market [30].

4. Conclusions

QFD is a typical PE tool which is primarily aimed at improving quality and reliability of processes and their outputs (products, services). Similar to other typical PE tools, it is characterised by its universality, flexibility and the openness. Such features facilitate its adoption to solve diverse decision making problems in civil engineering. These problems cover the full spectrum of civil engineering-related activities from building design through to the dismantling of used buildings.

Although the success of QFD applications in civil engineering can be assessed by several factors, it seems that two factors in particular deserve special attention. The first of these deals with promoting quality and reliability in building design and construction as well as in the usage, maintenance and dismantling of used buildings. The reliable consideration of customer needs and requirements is the second of these factors. This is why QFD facilitates satisfying stakeholders involved in all civil engineering-related activities.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

CIVIL ENGINEERING

DOI: 10.4467/2353737XCT.17.171.7279

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Production engineering tools for civil engineering practice – the case of FMEA

Narzędzia inżynierii produkcji w budownictwie – przypadek FMEA

Abstract

This article is the first of a series of papers which discuss the usefulness of production engineering tools for general civil engineering. Applications of selected production engineering tools in civil engineering are presented in these papers. The diverse nature of the tools is considered while outlining detailed areas of their application in civil engineering. The features of the tools make them representative of production engineering methodology. Thus, information about the civil engineering applications of the tools also makes it possible to draw practical conclusions about the general usefulness of production engineering methodology in civil engineering. The applications of failure mode and effect analysis (FMEA) are utilised in this regard in the article.

Keywords: civil engineering, construction, decision, support, production engineering, tool, application, FMEA

Streszczenie

Artykuł rozpoczyna cykl prac poświęconych użyteczności narzędzi inżynierii produkcji w szeroko pojmowanym budownictwie. Uwzględniając zróżnicowany charakter wybranych narzędzi inżynierii produkcji, przedstawiono w cyklu szczegółowe obszary ich zastosowań w budownictwie. Cechy wybranych narzędzi sprawiają, że dobrze ilustrują one metodykę inżynierii produkcji. Dlatego, na podstawie informacji dotyczących ich zastosowań w budownictwie, można sformułować praktyczne wnioski na temat przydatności metod inżynierii produkcji w budownictwie. W artykule wykorzystano w tym celu narzędzie FMEA (*failure mode and effects analysis*).

Słowa kluczowe: budownictwo, decyzja, wspomaganie, inżynieria produkcji, narzędzie, zastosowanie, FMEA

1. Introduction

Production Engineering (PE) deals with rules for the design of products and processes as well as with foundations of control, usage, organisation, and the management of manufacturing processes. Therefore, its scope fits in well with supporting typical civil engineering processes like design, construction, usage, maintenance and the dismantling of buildings. Typical civil engineering processes thus seem to be a natural area of extended application for PE tools. This is why PE tools are worth knowing and adopting for civil engineering purposes.

The practical nature of PE tools manifests in their ability to aid decision making in situations where the necessary information is hard to obtain and of poor quality; therefore, the application of tools may facilitate the exploitation of available imperfect information which would otherwise impede the decision-making process in civil engineering.

A general survey of PE tools is presented in the following section, a popular PE tool is then selected. The tool and its applications are presented in section 3 to illustrate the potential of PE methodology in civil engineering. A short discussion of the general usefulness of PE tools in civil engineering concludes the paper.

The discussion of the usefulness of PE tools in civil engineering will be continued in forthcoming papers – these papers will deal with other PE tools.

2. Production engineering tools

PE tools are important components of production management methodology. This is the main reason for calling them production management and engineering tools. A comprehensive survey of such tools is presented by Halevi [1]. He proposed applying two main criteria to categorise the tools. The first criterion deals with features of the tools. The application of the criterion results in the following tool categories:

1. Technical tools which require the application of hardware (T).
2. Software tools which require computer-based systems (C).
3. Organisation and management improvement tools (M).
4. General management concepts (P).
5. Auxiliary tools which support achieving detailed goals (X).

The second criterion deals with the general goals of the tools. The following tool categories are obtained by means of the application of the second criterion:

1. Providing hardware basis for relevant activities (T).
2. Providing techniques for achieving general goals (X).
3. Production planning and control (X, M, P).
4. Progress in production management (P).
5. Production process implementation (M, P).
6. Market tools (P, M, S).
7. Organisational tools (X, M, P).
8. Extension of conducted analyses (M, P).

9. Product design (M, X, P, T).
10. Human resources management (P, M).
11. Environmental management (P, M).
12. Quality improvement (X, M).

Note that symbols included in parentheses refer to the five groups of tools which result from the application of the previous criterion.

Halevi [1] mentions the following most interesting areas of application for PE tools:

1. Project planning and on-time project *completion.*
2. Reduction of production costs and product lead time.
3. Agile product design to speed-up its adoption to changing market needs.
4. Quality control based on defect-free production.
5. No stock policy-based product turnover intensification.
6. Improvement in the following construction enterprise activities:
   - internal communication due to knowledge and information management;
   - cooperation within task teams;
   - relationships with customers and suppliers;
   - management and control of procurement processes;
   - management of human resources;
   - integration in a construction enterprise and a supply chain.
7. Market competition and globalisation-aware strategic planning
8. Continuous improvement
9. Environment-friendly production
10. Expansion of market share.

The above-mentioned application areas may be considered in PE within the following dimensions:

1. Organisational dimension.
2. Product life-cycle dimension.
3. Effectiveness measurement dimension.
4. Management function dimension.

The numerous tool categories and tool application areas confirm the diversity and potential of the PE methodology. The diversity of PE tools makes the selection of a proper tool a cumbersome task; therefore, Halevi [1] proposed several approaches for the single criterion and multiple criteria identification of the most suitable PE tool. These approaches consider several contexts of the application of PE tools while recommending the most suitable tool for a given task. The contexts deal with:

1. Hardware.
2. Software.
3. Production planning and control.
4. Advanced production management.
5. Manufacturing methods.
6. Marketing.
7. General organisation.

8. Advanced techniques of manufacturing organisation.
9. Product design techniques.
10. Human factors in manufacturing.
11. Environment-friendly manufacturing techniques.
12. Manufacturing quality techniques.

The suitability of many presented application areas of PE tools seems to promote the successful application of the tools in comprehensive civil engineering practice. Applications of PE tools are presented in the next section to support this statement.

3. The application of selected PE tools in civil engineering

3.1. Introduction

The improvement in quality and reliability of products, processes and services are fundamental goals in the application of PE tools [2]. The necessity for urgent total quality management (TQM) implementation in civil engineering was articulated in the early nineteen-nineties [3, 4]. This is why improvement in quality and reliability is very important for civil engineering practice.

The concept of TQM is based on the observation that people, together with their motivations, culture, and willingness to take part in team work, make decision regarding the quality of products and services. Therefore, the main feature of the concept deals with engaging all organisation members into activities which lead to the long-lasting customer satisfaction and general benefits both for themselves and for society. Farooqui & Ahmed [5, 6] proved that TQM is also an effective tool for forming ethical attitudes and leadership in a construction enterprise. It also proved to be a useful tool for implicit cost control of the implementation of a construction project [7].

The attractiveness of PE methodology with regard to improvement in quality and reliability is especially evident in the case of typical PE tools such as FMEA (failure mode and effect analysis). This is why applications of FMEA are considered in the remaining part of this section to illustrate the usefulness of PE tools in civil engineering. The detailed usefulness of other PE tools will be discussed in forthcoming papers.

3.2. Applications of FMEA

The main goal of applying FMEA is concerned with improvement in the reliability of products, services and processes. Achieving this goal is assisted through the identification of the most important causes of registered failure modes. This identification is achieved through the quantitative description of causes and effect relationships, i.e. through the description of failure modes (Fig. 1). A set of three distinct and dimensionless variables constitute the description. The variables express severity (S), occurrence (O), and detectability (D). The overall importance of the relationship between a given failure mode and its cause is expressed by the risk priority number (RPN):

$$RPN = S \cdot O \cdot D \tag{1}$$

The higher the *RPN*, the more important the relationship (and the related failure mode) is.

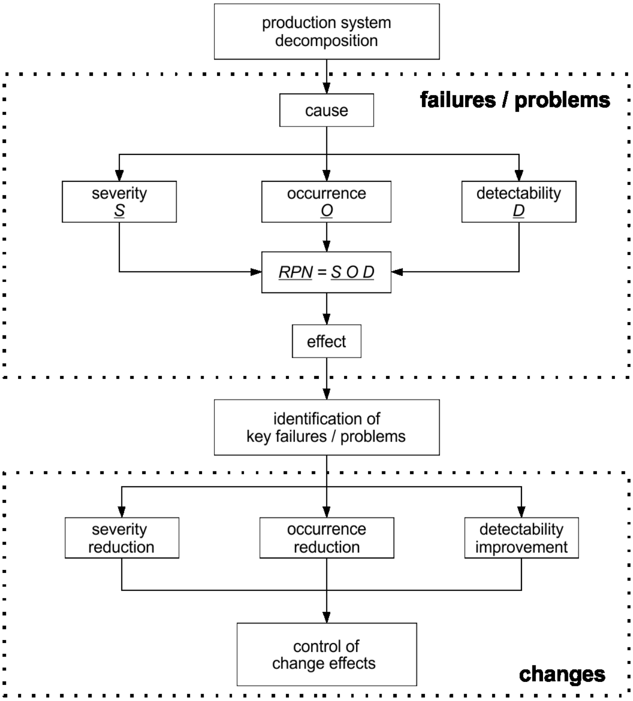

Fig. 1. FMEA procedure

The universal nature of FMEA results in the possibility of its application at different stages of the product life cycle [8]; therefore, civil engineering may benefit from the use of FMEA during planning and construction as well as during usage, maintenance and dismantling of buildings. There are almost forty records available in the well-known Scopus bibliographic database – this database considers the usefulness of FMEA for solving decision making problems in civil engineering. A description of selected applications of the tools follows below.

The FMEA tool is applied in civil engineering both alone and together with other tools for mutual enhancement; the tool itself has also undergone several enhancing modifications. These enhancements, both through being used in combination with other tools and through being modified, are utilised in almost half of all FMEA applications in civil engineering. The diversity of standalone, unenhanced applications of the tool is sufficient to characterise the usefulness of the tool for civil engineering; illustration of the usefulness of the tool is limited, therefore, only to such applications.

Initial applications of FMEA in civil engineering dealt with the preparation of cost-effective building maintenance strategies [9] and the selection of appropriate means for dealing with soil erosion and settlement control during roadworks [10].

Back in 2010, the FMEA was declared a promising tool for risk assessment in civil engineering [11]. Validity of the declaration was confirmed by numerous applications, for example [12, 13]. The detailed goals of such applications are as follows:

- prioritising measures which reduce accident risk in construction and the assessment of their effectiveness [14];
- improvement in the implementation of investment projects through the integration of risk assessments which deal with worker safety, environmental safety and quality [15];
- management of risk in the implementation of a construction project taking into consideration risk identification, assessment, analysis and monitoring as well as planning remediation activities [16];
- the identification of key risk factors in road construction projects relating to private-public partnerships [17];
- environmental risk assessment in water dam usage [18].

FMEA was also applied in civil engineering according to its original purpose. It enabled the identification of:

- damage mechanisms in concrete structures resulting from earthquakes [19];
- failure modes for earth anchor structures and responsibility for them [20].

Other FMEA applications pertained to management support are concerned with:

- building safety development [21];
- the assessment of barriers to innovation in order to facilitate their elimination due to skilful management of stakeholder competencies [22];
- technical infrastructure maintenance [23].

Current trends in the application of FMEA within civil engineering deal with the identification of key factors for:

- conflicts in construction project implementation [24];
- resolution of contract disputes [25];
- raising funds for the construction of modular structures [26];
- the degradation of external composite thermal insulation [27].

4. Conclusions

FMEA is a typically used PE tool, it therefore effectively characterises the potential of all PE methodology. Results of up-to-date FMEA applications in civil engineering confirm the features that are typical of PE tools, namely: universality, flexibility and openness. The features facilitate the easy adaptation of the tools to the needs of decision-making processes in civil engineering; this is due to:

1. The universality of the tools which makes them suitable for supporting the preparation and implementation of construction projects, exploitation of buildings and the dismantling of used buildings;
2. The flexibility of the tools which facilitates the consideration of imperfect information regarding the influence of the surrounding environment on construction, maintenance, dismantling processes etc.;

3. The openness of the tools which promotes their enhancement, either by improving the tools themselves or through using them in conjunction with other tools – both kinds of enhancements may contribute to further developments and expansions of the range of applications of PE tools within civil engineering.

PE tools are especially aimed at the improvement of the quality and reliability of products, services, and processes; therefore, the introduction of these tools within civil engineering promotes quality and reliability in building design and construction as well as in usage, maintenance and the dismantling of buildings.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

CIVIL ENGINEERING

DOI: 10.4467/2353737XCT.17.173.7281

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The concept of the composition of self-compacting concrete with low hardening heat

Kształtowanie właściwości betonów samozagęszczalnych o niskim cieple hydratacji

Abstract

This paper presents a proposal for shaping the properties of green self-compacting concrete, mostly focussing on minimising the amount of clinker in concrete and obtaining lower hardening temperatures. The main application of this SCC would be in constructions build during summer, as well as in massive and semi-massive structures. In these kinds of constructions, thermal effects connected with cement hydration are of particular importance. The difference in temperature between the interior and the relatively fast cooling exterior of the concrete element leads to thermal stress. In extreme conditions, this can cause cracking within the entire bulk of concrete element, leading to a lowering of its durability and longevity.

Keywords: self-compacting concrete, heat of hydration, massive structures

Streszczenie

W artykule przedstawiono koncepcję doboru składników mieszanek betonów samozagęszczalnych o niskim cieple hydratacji. Takie mieszanki są wykorzystywane do realizacji konstrukcji masywnych, a także do realizacji prowadzonych w warunkach podwyższonych temperatur. W konstrukcjach masywnych, efekty cieplne związane z reakcją hydratacji mają szczególne znaczenie. Różnica temperatur pomiędzy wnętrzem a powierzchnią konstrukcji prowadzi do powstawania naprężeń termicznych. W ekstremalnych warunkach prowadzić to może do zarysowania konstrukcji w całej jej objętości. Prowadzi to do obniżenia trwałości konstrukcji, a w przypadku masywnych fundamentów obciążonych dynamicznie może je całkowicie dyskwalifikować.

Słowa kluczowe: beton samozagęszczalny, ciepło hydratacji, konstrukcje masywne

1. Introduction

The composition and constituents of SCC are chosen on the basis of its rheological properties, taking into consideration the requirements of the construction with regard to concrete. SCC has to fulfil the following requirements: fresh concrete fluidity, which has to guarantee swift and precise filling of the form and covering of reinforcement; self-deaeration, which is its ability to quickly remove air from the concrete mix; stability, which is the resistance of the concrete mix to segregation [1].

The requirements of concrete mix fluidity and self-deaeration can be fulfilled by lowering the yield and plastic viscosity of the fresh concrete (or increasing the spread D_{max} and reducing the spread time T_{500} according to a slump flow test). The lower the yield, the lower the height of a concrete mix column which causes its flow, and the faster and more efficient its deaeration and levelling in a form or formwork. The lower the plastic viscosity of the concrete mix, the shorter the time concrete mix needs to fill a form and deaerate. Unprompted sedimentation of the aggregate decreases when the plastic viscosity increases; however, it increases with larger aggregate grains and higher differences between the densities of the aggregate and the cement paste. Achieving a compromise between the conflicting requirements of fluidity and self-compaction, thus obtaining suitable rheological properties of the concrete mix, is the single biggest challenge during the process of designing a concrete mix. It is assumed that for the sake of the fluidity requirement, the yield should be as low as possible. At the same time, the plastic viscosity should be chosen so that the concrete mix properly and quickly fills the mould and that the air is effectively removed with a minimum of segregation.

The necessity to meet the rheological criteria determines the need for a specific composition and combination of constituents of the self-compacting concrete. First and foremost, assumed are: small w/(c+a) ratio (w – water, c – cement, a – mineral additives), and a large amount of fine fraction (< 0.125 mm), which includes fine aggregate, as well as cement and mineral additives (stone powder, ground granulated blast furnace slag, fly ash and others). Mineral additives allow to increase the amount of cement paste without increasing the amount of cement over the necessary minimum. Due to the fact that the presence of additives helps to reduce the amount of cement in the concrete, the amount of heat generated during hydration is reduced. By properly choosing the type and amount of additives, it is possible to regulate the technical properties of concrete. A low w/c ratio and a high content of dust fractions reduce the amount of free water in the concrete mix – this increases its resistance to segregation and sedimentation.

Typical self-compacting concrete is characterised by a w/c ratio < 0.50, w/(c+a) < 0.35, a fine fraction content from 500 to 600 kg/m^3 and a volume of cement paste from 300 to 400 dm^3/m^3 or even higher. The right fluidity is obtained through use of effective superplasticizers, usually based on polyethers. Moreover, in order to reduce the risk of segregation of the concrete mix and to obtain an appropriate degree of flow, rounded, regularly shaped gravel is used; its maximal size should not exceed 20 mm (usually 10–16 mm) and its sand content should be 40–50%. In order to eliminate or reduce the segregation and the leakage of cement paste from fresh concrete, and to lower its pressure on the formworks, it is recommended that viscosity increasing admixtures be used. The presence of such admixtures also decreases the susceptibility of fresh concrete to changes in the amount of water. Due to the technological simplicity of adding admixtures to a degree, they can pose as an alternative to the use of mineral additives – they allow the improvement of the stability of the fresh concrete without the need to interfere with its basic composition.

Proper selection of the constituents of the fresh concrete is also essential for the building of massive structures. The concrete composition is calculated so that the amount of heat generated by cement hydration is minimised whilst taking into consideration the requirements of the concrete with regard to construction [2]. Due to the fact that cement is the constituent that determines the amount of generated heat, it is necessary to use cements which produce low levels of hydration heat and to try to limit their content to the necessary minimum.

In practice, for concrete in massive structures, amount of cement for 1 m^3 of concrete does not exceed 300 kg/m^3. In order to further limit the amount of heat generated during the hardening of the concrete, mineral additives are used as a substitute for the part of cement – the best results are obtained by using fly ash or ground granulated blast furnace slag. Because of the necessity to limit concrete shrinkage and to provide adequate impermeability of the cement matrix and adequate durability of the concrete construction, it is best to use a w/c ratio lower than 0.5 (however, to keep of the amount of heat generated to a minimum, the w/c ratio can be higher). Because of the need to obtain this ratio, it is necessary to use plasticisers and superplasticizers to acquire the right workability. Retarding admixtures are used in order to delay the setting time and to spread the heat production over the course of time.

Due to the minimisation of the amount of cement (and cement paste) it is beneficial to use aggregate with the largest possible grain size and an amount of sand not exceeding 30–35%. It is worth noting that because of the technological factors and the possibility of causing tension in the element, aggregate grains should not be larger than 31.5 mm. An important consideration is the choice of an aggregate which has appropriate levels of thermal conductivity and coefficient of thermal expansion. The best properties in this regard are displayed by gravel aggregate, and to a lesser extent granite and limestone aggregate.

As can be observed, the compositions of both SCC and concretes for massive structures easily fall within the definition of 'green concrete' [3, 4]. Obtaining SCC that generates low hydration heat is not, however, an easy task. Primarily, the amount and composition of the cement paste must be optimised in such a way that allows the fulfilling of both the requirement of self-compaction (in which a higher quantity of cement paste is desirable) and the minimisation of the amount of heat generated (in which a lower quantity of cement paste is desirable). Another important consideration is the choice of aggregate grading – this choice should be made in such a way that the requirements of self-compaction can be met with the realistically lowest content of sand and the largest possible size of aggregate grains. The general concept of the composition of SCC which generates low levels of hydration heat is presented in Fig. 1.

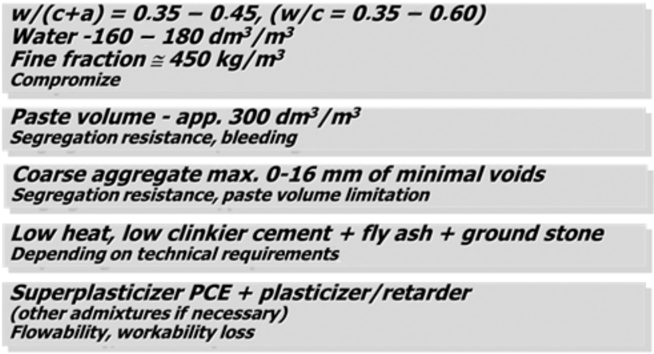

Fig. 1. The technical requirements green SCC generating low hydration heat

It is assumed that the amount of the cement paste in this concrete should not exceed a level of around 280–300 dm^3/m^3, meaning it should not vary from the amount of cement paste in mechanically compacted concrete. With this amount of cement paste, by appropriately choosing the w/c ratio, type and amount of cement and type of mineral additives, it is possible to more or less freely shape the rheological properties of the fresh concrete, the amount of heat generated during the hardening process, and the properties of the hardened concrete. It is also possible to fulfil the requirements of concrete standards that apply to 300–350 kg/m^3 of cement with a w/c ratio of 0.45–0.60 which result from the exposition class dependant on the environmental conditions according to PN-EN 206.

It should be noted that using a w/c ratio > 0.5 allows lowering the degree of hydration heat generated and inhibiting the kinetics which result from hydration heat generation in the early phase of hydration – this is beneficial due to the early thermal effects in the massive concrete structure. If expected properties of hardened concrete allow, it is beneficial to set as high a w/c ratio as possible.

The necessity to guarantee the required stability of the SCC mix imposes the use of aggregate with a maximal grain size of 16 mm. This presents certain problems with regard to the minimisation of the amount of cement paste and requires careful selection of the aggregate grading to minimise the content of empty voids. Use of gravel aggregate is the optimal choice considering the requirements for SCC and massive concrete structures.

It is assumed that the required rheological properties of fresh concrete can be obtained through the use of a carefully selected superplasticizer, thus avoiding the use of viscosity enhancing admixtures. It should be noted that air-entraining of fresh concrete can be used as a way of decreasing the amount of cement (binder) in the concrete – this is beneficial with regard to the amount of heat generated (however, it may impede the extent to which its workability can be shaped). In order to achieve this effects, air-entraining cements or admixtures may be used.

2. Research methodology and compositions of mixtures

During the research, the possibility of obtaining self-compacting concrete which generates low levels of hydration heat according to the above-mentioned requirements was investigated. When selecting the amount and type of binder, the objective was to minimise the use of clinker in the concrete; therefore, cements with low levels of clinker were used – these included new, air-entraining cements which had not been previously used in Poland. The amount of cement was also minimised by substituting it with various combinations of high-calcium fly ash, limestone and silica fume.

Table 1. Composition of concrete

Content	B0	B1	B2	B3	B4	B5	B6
CEM I 52.5 N	451						
CEM III/B 42,5 L-LH		306			238	250	253
CEM V AS-V			297				
CEM V AS-V AEA				277			
Calcareous Fly Ash					104		
Quartz Meal						135	
Limestone							125
Sand 0-4	800	969	946	881	998	997	880
Coarse aggregates 4-11	437	363	354	330	372	374	420
Coarse aggregates 8-16	538	451	440	410	468	464	490
Water	171	193	187	174	151	158	160
SP Glenium SKY 591 [kg]	3.91	2.90	3.89	5.05	7.78	5.45	5.28
$w_{eff}/(c+a)$	0.38	0.63	0.63	0.63	0.44	0.41	0.42
w_{eff}/c	0.38	0.63	0.63	0.63	0.63	0.63	0.63
Volume of cement paste $[dm]^3$	320	294	289	268	270	293	291

About five million tons of calcareous fly ash is produced annually in Poland as a result of brown coal combustion in conventional boilers. The results of studies [5, 6] show no negative influences of HCFA on the properties of hardened concrete. The main problem with the practical use of HCFA is that its inclusion significantly worsens the workability of fresh concrete, especially in the aspect of workability loss.

However, it has shown that the negative influence of CFA on the workability of fresh concrete may be reduced through the application of a grinding process and even the obtaining of SCC with HCFA is possible [4, 5]. Among the variants of concrete tested (Table 1) there were concrete mixes which included sand and gravel aggregate with the fraction grading shown in Fig. 2. SCCs were designed using the method presented in [7].

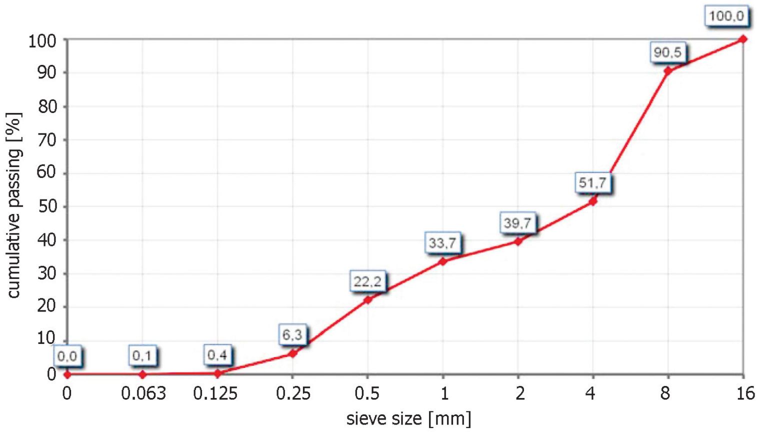

Fig. 2. Aggregate grading curve

Fresh and hardened concretes were tested for:

- Properties of fresh SCC – measurements were performed at a temperature of 20°C at 5 and 60 min after the completion of mixing using the slump-flow test according to EN 12350-8. The stability of each mixture was evaluated using the Visual Stability Index (VSI; according to ACI 237 R-07; 2007). Additionally, the air content in the mixture at 5 min after mixing was determined according to EN 12350-7.
- Setting time of concrete – measurements were performed using an ultrasonic method by means of the Schleibinger Vikasonik system. The transmitter and receiver were placed on the sides of the 25 cm cubes which were tested for the progress of concrete hardening temperature.
- Progress of concrete hardening temperature – measurements were performed on 25 cm cubic samples on a face which was insulated using polystyrene foam coating with a thickness of 100 mm and a thermal conduction coefficient of 0.044 W/m·K (Fig. 3). Temperature measurements were taken from the centre of the cubes. The external temperature during the performing of measurements was 20°C.

Fig. 3. Sample of fresh concrete with thermal insulation and the Vikasonic system as prepared for measurement

- Compressive strength after 2, 7 and 28 days – measurement were performed according to PN-EN 12390-3, samples were cured according to PN-EN 12390-2.
- Hydration heat – for binders and admixtures used in the tested concretes, hydration heat and hydration kinetics were measured using the Tam Air isomeric calorimeter produced by TA Instruments. Measurement was performed on the cement (binder) paste over a 72-hour period with superplasticizer content analogous as in concrete. Measurement was performed at a temperature of 20°C.

3. Test results and discussion

The obtained results are compiled in Tables 2 and 3. The highest amount of generated heat during the hydration process was clearly obtained for samples with the B0 binder (Portland cement CEM I and SP). Samples which contained the other binders produced significantly lower hydration heat and kinetic activity associated with its generation – the amount of heat generated is mainly dependent on the amount of cement clinker and specific surface area. The smallest amount of heat generated during the hydration of ground granulated blast-furnace slag cement occurred with samples using the CEM III/B 42,5 L-LH binders. Composite cement CEM V/A (S-V) with AEA has a lower amount of heat at the first stage of hydration than CEM V/A (S-V) without the addition of AEA.

Self-compacting concretes of slump flow class SF2 and viscosity VF2 were obtained. These properties were generally sustained at a stable level for at least one hour. This also applies to the concrete mixes which contained high-calcium fly ash (B4); however, in this case, it is necessary to increase the quantity of superplasticizer which is added. The concrete, excluding the concrete with air-entraining cement which has an air-content of 11%, has an air-content at the level of 2%. The use of cements with mineral additives in concrete composition and the introduction of mineral additives in place of portion of the cement delays the setting time in comparison with the SCC mixture with CEM I cement – the delay amounts to 50–100% (3–6 h). The longest delay was observed for concrete B4 with cement CEM V/A (S-V) with the addition of AEA.

Use of cement with mineral additives and mineral additives themselves have significantly lowered the maximal hardening temperature of concrete from approx. 60°C for concrete with cement CEM I to approx. 40°C for concretes with CEM V/A (S,V) and approx. 30°C for concretes B2, B4, B5 and B6 with CEM III/B. Using cement CEM III/B is particularly effective, whereas using mineral additives with this cement only influences the concrete temperature to a lesser degree. Using air-entraining cement affects the temperature of hardening to a rather small degree. Using cements CEM III/B and CEM V/A (S,V) did not significantly increase the time taken to reach the maximal temperature of concrete in comparison to CEM I concrete. However, in the case of using mineral admixtures as a replacement for cement CEM III/B, the maximal temperature was recorded to have been reached from 14 to 22 hours later than in the concrete with cement CEM I.

Table 2. Research results

Property	B0	B1	B2	B3	B4	B5	B6
Slump flow after 5 min [mm]	705	680	650	620	650	670	695
Slump flow after 5 min [mm]	680	670	600	550	600	660	670
Flow time T_{500} after 5 min [s]	2.3	2.7	3.0	2.1	6.0	5.2	5.4
Flow time T_{500} after 60 min [s]	2.7	2.9	3.2	4.0	7.4	6.7	7.0
Air content A_C [%]	2.1	1.5	2.5	11.0	1.3	2.0	1.7
Initial setting time [h]	6:36	10:04	9:52	17:09	12:00	10:12	9:43
Maximal temperature [°C]	57.9	34.8	39.7	37.2	32.2	30.0	29.8
Time of maximal temperature	29:54	36:55	33:50	35:41	51:28	45:56	43:56
Compressive strength after 2 days [MPa]	25.3	2.3	2.0	0.8	4.9	1.2	2.0
Compressive strength after 7 days [MPa]	48.6	25.4	22.7	13.5	36.0	31.0	29.4
Compressive strength after 28 days [MPa]	57.8	41.4	38.9	25.2	48.3	44.8	42.5

Table 3. Test results – cement + additive hydration heat [J/g]

Concrete	1h	2h	12h	24h	72h
B0	10.54	13.25	38.37	75.84	201.06
B1	8.95	10.92	22.70	32.31	151.64
B2	2.72	3.55	6.42	10.51	119.1
B3	3.77	5.21	9.56	17.48	120.02
B4	7.84	10.66	22.43	30.19	106.05
B5	6.70	8.41	13.31	19.69	81.83
B6	9.53	10.96	16.29	25.26	94.72

As could be expected, the compressive strength of concrete with cements CEM III/B and CEM V/A (S,V) and with the mineral additives is low and amounts from approx. 1 to 5 MPa after 2 days. However, after 7 days, it amounts to from 23 to 36 and the highest is for concrete containing CFA. After 28 days, there were compressive strengths of 38.9 MPa for CEM V/A and 42–47 MPa for CEM III/B concretes, which should be considered to be very satisfactory (usually concrete classes of up to C30/37 are specified for concretes used for massive structures). Due to high air entrainment, concrete with air entraining cement CEM V/A clearly has lower compressive strength in all measuring terms (after 2, 7, 28 days).

It was reconfirmed that despite the negative influence on workability, high-calcium fly ash which underwent the grinding process can be used for self-compacting concretes – its presence has either a zero or positive effect upon the remaining concrete properties. Air-entraining cements can be also used; however, in the case of these, problems may occur regarding control over the air content and, consequently, substantial losses in compressive strength – the air content is dependent upon the amount of cement and cannot be controlled by changing the amount of admixture.

4. Summary

Designed according to the proposed concept, self-compacting concretes are characterised by their low content of clinker, amounting to from 60 to 133 kg/m^3, and their good strength properties. It can also be assumed that these concretes, due to their high content of blast-furnace slag, are also characterised by adequate durability; however, this requires further experimental verification.

It was proven that by optimising materials and concrete mix design, one can obtain green self-compacting concrete which is characterised by a low hardening heat and good mechanical properties over longer periods of hardening. This kind of concrete performs well, especially in massive structure elements. Ground high-calcium fly ash can be used for self-compacting concrete without negatively affecting the properties of the concrete after hardening.

Using air-entraining cements for concrete enables decreasing the amount of heat generated by concrete during hardening (approximately 7% lower maximal temperature of air entrained concrete was observed). The range of their use can also include concrete elements of considerable size; however, it should be note that when using air entraining cements, it is difficult to control air entrainment and the compressive strength of concrete.

Acknowledgments

The results presented in the were obtained from the project 'Innovative cement binders and concretes with addition of high calcium fly ash' (project no POIG.01.01.02-24- 005/09 with the Polish Ministry of Science and Higher Education) in the framework of the Operational Programme Innovative Economy 2007–2013.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

CIVIL ENGINEERING

DOI: 10.4467/2353737XCT.17.174.7282

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An overview of selected methods for the identification and qualitative assessment of risk factors

Przegląd wybranych metod identyfikacji oraz oceny jakościowej czynników ryzyka

Abstract

The problematic nature of the identification and assessment of the risk factors is a familiar subject area. As a result of this, many scientists are continually attempting to modify existing methods and develop new approaches to achieve this objective. Therefore, it is recommended to periodically review the methods used – this reveals areas of knowledge in this area which remain undeveloped and also determines which methods can complement or verify each other. In this article, current methods for the identification and qualitative assessment of risk factors are described and compared in a tabular manner; the author also proposes potential approaches for the modification and improvement of these methods.

Keywords: risk management, qualitative analysis

Streszczenie

Identyfikacja oraz ocena jakościowa czynników ryzyka jest szeroko znanym zagadnieniem. Przekłada się to na częste modyfikowanie istniejących oraz opracowywanie nowych narzędzi do tego służących. W związku z tym wskazane jest, aby co pewien czas dokonać przeglądu stosowanych metod. Pozwala to wydzielić jeszcze niezagospodarowane obszary wiedzy w tym temacie, a także określić, które metody mogą wzajemnie się uzupełniać lub weryfikować. W artykule omówiono i porównano tabelarycznie obecnie stosowane metody identyfikacji oraz oceny jakościowej czynników ryzyka, a także przedstawiono potencjalne kierunki modyfikowania i ulepszania tych metod.

Słowa kluczowe: zarządzanie ryzykiem, analiza jakościowa

1. Introduction

The identification and assessment of the risk factors are among the first processes in the whole procedure of risk management (Fig. 1). These processes enable the identification of potential risks associated with a given project and aid the process of performing an initial risk assessment. As a result of this identification and assessment of risks, appropriate preventive actions can be taken to eliminate these risks or minimise the consequences of their occurrence [1, 13, p. 47–53].

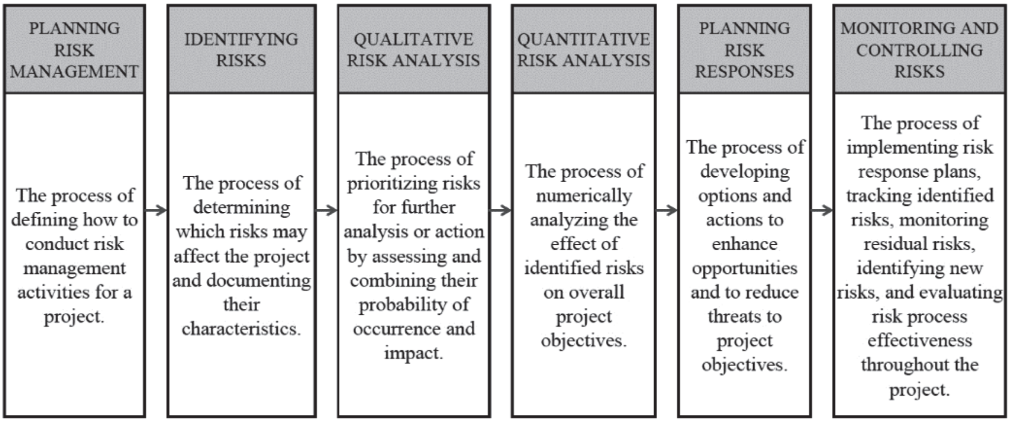

Fig. 1. Consecutive processes in risk management by PMBoK (based on [1])

The first methods of project management, as well as risk management, date back to the year 1942, when the relevant documents were prepared for the American program for the production of an atomic bomb (Manhattan Engineering District Project). Since then, the topic of risk management has been very popular among both theoreticians and practitioners around the world. Simplicity and ease of use of tools for the identification and qualitative assessment of risk factors results in a large number of modifications to them or the development of new, innovative solutions. Therefore, there is a need to periodically review the methods that are used. This enables the progression of the current level of knowledge, and also makes it easier to identify areas that remain undeveloped and that require further work and analysis. In addition, knowledge of the advantages and disadvantages of each method can help to evaluate which of these methods can be used to verify or complement others. The purpose of this article is to describe the currently used methods of the identification and qualitative assessment of risk factors, to present their comparison in tabular form and to suggest possible further directions for modifying and improving these methods.

2. Methods for the identification and qualitative assessment of risk factors

The identification and qualitative assessment of risk factors is usually prepared before the implementation of a given project. However, during works, analyses may be conducted again when new data is available [5, p. 4–15, 19, p. 43–49]. As a result, managers who direct works always have current data about the real risks that may potentially appear on the construction site. The advantages of the vast majority of tools used in this type of analysis are its simplicity of use and clarity of results; often, the main disadvantage is the analyses having a very subjective nature. Additionally, various methods have their own characteristic strengths and weaknesses [6, p. 76–77, 8, p. 307–324].

2.1. Surveys of expert opinions

Surveys of the opinions of experts are often used by academics [3, p. 963–972, 4, p. 1205–1213, 9, p. 59–62, 10, p. 107–111, 11, p. 157–166, 14, p. 332–339, 21, p. 120–129], this is mainly due to the chosen risk assessment method having a low level of complexity. To obtain the required results from surveys of experts, an appropriate set of questions needs to be produced – these are most often closed ended. The questionnaires are often clearly divided into two parts – the first group of questions concerns the respondent and is mainly related to their experience. This shows the respondent's professional practice and can confirm that the opinion of the person is in fact an expert opinion. The second group of questions concerns a problem which constitutes increased risk. Due to the closed nature of the questions, completing the survey takes only a short amount of time – this has a positive impact on the willingness of respondents to participate in the research.

The main difficulty related to using this method is obtaining a group of respondents that can be described as being representative. Furthermore, each group of experts should not be used too often as this may discourage them from participating in subsequent studies. The time required for survey is quite difficult to estimate and depends primarily on the time needed to supply questionnaires to people participating in the research. Depending on the intermediary in the supply of questionnaires (usually professional associations), it may take from a few days to even several weeks (in the case of strongly hierarchical structure of an organisation with a lot of stages in the decision-making structure). The main advantage of the method is the fact that due to way in which the questionnaires are supplied to the experts (usually electronically) it takes only a few hours to obtain a representative group of respondents.

2.2. Planning meeting for project stakeholders

The method requires the involvement of representatives of as many stakeholders as possible (Fig. 2) [8, p. 307–324]. They discuss the risks and the degree of their possible impact on the given project. The main advantage of this method is the fact that it uses the knowledge and experience of a group of experts which is advantageous because of their cooperation. Moreover, each stakeholder is made aware of the entire list of risks associated with the project from the beginning. However, the method requires very well-developed soft skills (e.g. the use of mediation, negotiation, discussion, etc.) from the person chairing the meeting – this enables the efficient progress of the whole process of risk assessment. If the leader does not have appropriate skills, the meeting may get out of control and take a turn for the worse. It is possible that there will be conflict on the assessment of some of the risk factors between holders of different opinions. It may also be difficult to determine who is responsible for each factor. One should also keep in mind that different individuals and they may try to reduce their own responsibility, rather than care about the whole project. The time required for analysis depends primarily on the goodwill of the team and the predisposition of the chairperson. Under favourable conditions, only one or two meetings may be required; however, in the absence of cooperative attitudes, it is possible that the analysis will be prolonged or may even totally fail.

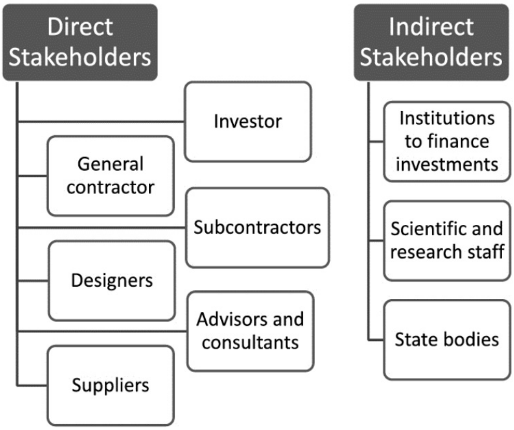

Fig. 2. Stakeholders involved in the process of investment and construction [own work]

2.3. Analysis of the documentation from completed projects

If the managing body conducts a qualitative analysis of a sufficiently large base of documentation from completed projects, it is possible to determine the risk factors and their potential impact on the project under analysis [7, p. 112–113, 16, p. 55–60]. While using this method, the size of the body of data available and the quality of its constituent documents is very important. The main documents are primarily construction logbooks – these should contain details of serious problems which appeared during the construction. The advantage of this method is its simplicity – one only needs to take a look at the problems that occurred in each project and then assess whether there is a risk of similar problems occurring on the planned construction. Moreover, the documentation may contain information on how to solve some of the problems. Unfortunately, for the method to be used effectively, it is necessary to obtain a sufficiently extensive body of data. Organisations with shorter industry experience do not have the opportunity to benefit from this tool. The duration of the analysis of the documentation of completed projects depends primarily on the size of the body of data and can range from just a few to several days.

2.4. The Delphi method

The Delphi method is a method very similar to surveys of expert opinions. It also uses external experts who share their knowledge and experience through questionnaires. The difference mainly concerns two aspects. Firstly, the Delphi method usually requires a series of several surveys; this is due to the fact that the experts who present different points of view to the majority are asked to verify their opinions again – these opinions can then be either modified or maintained. In situations where extreme opinions are maintained, the questionnaire is excluded from the research; as a result, the final product of the method is a single opinion of the group of experts. In surveys of expert opinions, discrepancies in results may be far greater. Extreme opinions are always eliminated in the Delphi method. The problem appears in the situation in which the extreme opinion is correct. The organisational aspect of surveys can also be problematic. The respondents can remain anonymous in typical surveys of expert opinions. In the Delphi method, it is required to collect contact details (usually e-mail addresses) of the respondents in order to verify their potential extreme positions. The time required for conducting the method is the time needed to supply the experts with the questionnaires plus the duration of subsequent iterations [18, p. 150–159].

2.5. Interviews with experts

This is one of the most time-consuming methods; however, the results can be very useful [15, p. 127–136]. The process requires organising a series of meetings with experts in the subject area. These meetings are organised individually, there is also the possibility of meeting experts again after obtaining information from other experts. This method enables a very high level of interaction with each expert as a result of one-to-one conversation – each issue is discussed in detail and uncertain issues are thoroughly explained.

2.6. Direct observation

With this method, the person or team assessing risk uses their own experience and knowledge [20, p. 5670–5677]. During analysis of the data received on a specific project (mainly design documentation, *contractual* agreements, information about stakeholders, etc.), the evaluator prepares a list of risk factors and the level of risk that they pose to the investment. The advantage of this method is the short duration of the study, depending upon the performance of the individuals or team conducting the analysis. The disadvantage is that it is subjective, relying upon unverified points of view on particular issues; therefore, this method is recommended to be used as an addition to other methods (e.g. interviews) for the purposes of verification.

3. Comparison of described methods

The described methods are used to obtain data that is necessary for qualitative analysis – their comparison is presented below in tabular form. Items that are included in this comparison are: the number of people involved in the research; the duration of data collection and analysis; the organisational difficulties; the quality of the results. The selection of these features stems from the basic limitations related to scientific research; these are mainly the time and the available human resources. Moreover, the methods with smaller organisational difficulties are recommended for people with a lower level of soft skills. Finally, the quality of the results may indicate that they should be verified by using another method.

Table 1. A tabular comparison of the described methods

Method	The number of people involved in the research	The duration of data collection and analysis	The organizational difficulties	The quality of the results
1	2	3	4	5
Surveys of expert opinions	Large number of people involved	Relatively long, dependent upon the goodwill of external stakeholders and experts	Difficulties in involving professional institutions	High quality of results obtained thanks to a large number of experienced respondents
Planning meeting of project stakeholders	Small number of people involved	Relatively short, dependent on the goodwill of external stakeholders	Difficulties associated with an appropriate meeting time for all stakeholders	The quality of the results depends upon the level of cooperation between stakeholders
Analysis of the documentation from completed projects	Single person or small group involved	Relatively short, dependent on the scope of analysed material	Difficulties in obtaining adequate numbers of documents	The quality of the results depends on the scope of issues contained in the documentation
Delphi method	Large number of people involved, but extreme opinions are rejected	Relatively long, dependent upon the goodwill of external stakeholders and experts as well as the number of iterations needed	Difficulties in involving professional institutions	High quality of results obtained thanks to a large number of experienced respondents

1	2	3	4	5
Interviews with experts	Small number of people involved	Relatively short, dependent upon the number of experts involved	Difficulties associated with scheduling an appropriate meeting time for each expert	The quality of the results depends on the number and level of expert knowledge
Direct observation	Single person or small group involved	Short, usually one to a few days	No special organisational difficulties	Results are subjective, the quality of which depends primarily on the experience and knowledge of the analysing person or team

The developed comparison shows some dependencies – the highest quality results are related to there being a large number of people involved in the research. Additionally, the duration of data collection is the longest and the organisational difficulties are the largest when there are a large number of people involved. Methods that involve a smaller group of people usually require less time; however, with such cases, the results may need to be verified by another method.

4. Tools for presenting the results of qualitative analysis

When data collection and analysis have been completed, the results of the qualitative assessment of risk factors should be presented [12, p. 545–550]. For this purpose, four basic tools are used:

- a list of the probability of the occurrence of different risk factors and their potential impact (a descriptive scale is used to achieve this, e.g. very high, moderate, low and very low);
- matrix assessments of the likelihood and consequences of the materialisation of risk factors (depending on the needs, linear or logarithmic scales are used.);
- presentation of the complexity of the project (the stability of the design assumptions and the possible effects of the impact of errors in their formulation is assessed);
- ranking of data accuracy (the accuracy and objectivity of the data used in planning are studied).

Matrix assessments of the likelihood and the consequences of the materialisation of risk factors are the most popular methods. This is mainly due to the fact that in addition to evaluation of the use of numerical or linguistic variables, the results are also presented in graphical form; as a result of this, the analysis of the risks is easily understood even for people without wide engineering or managerial knowledge. Furthermore, this method can be easily modified; one of the options for modification is the inclusion of additional parameters that characterise the risk factor. For example, a threat to life or health of workers [17, p. 2073–2080] or a proximity of the possible date of materialization of a risk factors [2, p. 2179–2184]. However, the inclusion of additional parameters requires modifications to previously used models of qualitative assessment of the impact intensity of individual risk factors.

5. Summary and conclusions

The main advantage of the qualitative assessment of risk is its simplicity of use and the clarity of results. However, the disadvantage is the subjective nature of the obtained data. Understanding the strengths and weaknesses of each method enables the identification of which methods can complement or verify each other. A series of tools has also been developed to present the results of the qualitative assessment. Among these, Matrix assessments of the likelihood and the consequences of the materialisation of risk factors are the most often used – this tool can be continuously modified. One of the options for these modifications is based on considering additional parameters that take the risk factor into account. This enables a better understanding of the impact of a given risk factor on the outcome of the project, thus increasing the credibility and usefulness of qualitative risk analysis.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017
CIVIL ENGINEERING
DOI: 10.4467/2353737XCT.17.175.7283

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The influence of foundation for the initiation and growth of the landslidein the Carpathian flysch

Wpływ warunków posadowienia na inicjację i rozwój strefy osuwiskowej we fliszu karpackim

Abstract

The southern part of Poland is mostly covered by Carpathian mountains. Carpathian Flysch is especially predisposed for the landslides type of the subsoil. Around 98% of all occurring in the country landslides are located in Carpathians. Many of them became active in May 2010, when periodically dormant landslides and new landslide were activated after intensive rainfall. In addition to the main causes of landslides such as rainwater and its infiltration into the ground layers also the Carpathian Flysch tectonic construction (rock layers collapsing in one direction, with numerous jumps and discontinuity) and some anthropogenic influences (loading, slopes undercutting, improper dehydration, etc.) are typical triggering factors. Landslide activity contributes not only to a significant progress of the relief to which occur, but it also carries devastating consequences for the population living nearby. Landslides are a natural threat for economic activities and people's lives. They are the cause of the damage not only residential buildings but also road and railways and other infrastructure. The landslide analysed here is located in Tymbark, Limanowa district. This article discusses the influence of the building foundation for initiation and growth of the landslide zone in the Carpathian Flysch. Two types of foundations are analysed – base plate foundation and a continuous footing. In both cases, there is a high risk to occur slip zones (FoS < 1.5). Base plate turns out to be more favorable foundation in this subgrade conditions. Although the displacements are relatively larger than in the other case, slip zone is located quite shallow. In the case of the continuous footing, landslide may form deeper reaching the bedrock.

Keywords: landslides, Carpathian flysh, numerical model, stability analysis, MIDAS

Streszczenie

Szczególnie predysponowanym obszarem na terenie Polski do powstawania osuwisk są Karpaty fliszowe. Właśnie na tym obszarze zlokalizowanych jest ok 95% wszystkich osuwisk występujących w kraju. Wzmożona aktywizacja osuwisk na tym terenie miała miejsce w maju 2010 roku, kiedy po intensywnych opadach atmosferycznych doszło do aktywizacji wielu okresowo nieaktywnych osuwisk oraz do inicjacji nowych stref osuwiskowych. Oprócz głównej przyczyny powstawania osuwisk jaką jest woda opadowa oraz jej infiltracją wgłąb warstw gruntowych wyróżnić możemy również budowę tektoniczną Karpat fliszowych (warstwy skalne zapadające się w jednym kierunku, liczne uskoki i nieciągłości) oraz wpływy antropogeniczne (obciążenie, podcinanie skarp, błędne odwodnienie itp). Aktywność osuwisk przyczynia się nie tylko do znacznego rozwoju rzeźby terenu w jakim występują, ale również niesie za sobą katastrofalne skutki dla ludności zamieszkującej pobliskie tereny. Osuwiska są naturalnym zagrożeniem dla działalności gospodarczej oraz życia ludzi. Są przyczyną uszkodzeń nie tylko budynków mieszkalnych ale również m.in. elementów infrastruktury drogowej i kolejowej. Analizowane osuwisko zlokalizowane jest w Tymbarku, w powiecie limanowskim. W artykule omówiono wpływ warunków posadowienia na inicjację i rozwój strefy osuwiskowej we fliszu karpackim. Przeanalizowano dwa przypadki posadowienia obiektu budowlanego – posadowienie na płycie fundamentowej oraz na ławach fundamentowych. W obu przypadkach istnieje duże ryzyko wystąpienia stref poślizgu (FoS < 1,5). Korzystniejszym warunkiem posadowienia okazuje się płyta fundamentowa. Pomimo, że występujące przemieszczenia są stosunkowo większe od przemieszczeń w przypadku posadowienia na ławach fundamentowych mamy do czynienia ze strefą osuwiskową zlokalizowaną dość płytko. W przypadku posadowienia na ławach fundamentowych może dojść do wystąpienia głębokiego, strukturalnego osuwiska sięgającego warstw skalnych.

Słowa kluczowe: osuwiska, flisz karpacki, model numeryczny, analiza stateczności, MIDAS

1. Introduction

Carpathians, due to the complicated geological structure, is an area in Poland where the most active landslide zones are located. It is estimated that in the Carpathians, with the surface just 6% of the country, approximately 95% of all landslides occurring in Poland is located [4]. Alternating stacked layers of permeable sandstone and poorly permeable shales, claystone's and marls, as well as the presence of steep slopes, increase the risk of landslides. Many landslides were triggered in May and June 2010. A number of buildings, including residential houses, industrial facilities, road infrastructure and railways were destroyed as a result of terential rainfall.

2. Significant causes of mass movements

One of the main factors influencing the activity of mass movements is undoubtedly detrimental effects of water flow. The occurrence of landslides in the area of the Carpathian Flysch is associated with complicated meteorological and hydrological conditions. Violent rain, spring thaw and long, wet and cold periods lasting several months are particularly dangerous. Water, which is then stored in weathered caverns and bedrock, contributes to the formation of a deep structural landslides [1]. Therefore, infiltration of rainwater is considered as the main cause of deterioration of the strength properties of soil and initialization of landslide movements. The slope stability is also influenced by factors such as frost and thawing of soil, undercutting slopes (eg. abrasion), shock (eg. earthquake), as well as the propagation of cracks and crevices, suffosion or weathering.

One should also pay attention to the anthropogenic factors. Direct and indirect human activities are equally important factors in the analysis of mass movements, which is often ignored. Load on steep slopes by constructing buildings and undercutting the slopes by conducted operational and engineering works are the most dangerous factors. The influence of dynamic loading is also significant. It can be triggered by e.g. work heavy machinery or blasting.

Complicated structure of the Carpathian Flysch has also undoubtedly the influence on the occurrence of landslides. Rock-layers collapsing at the same angle in one direction and the discontinuities of any size favour the formation of the gravitational mass movements. As a measure of stability in view of the equilibrium limit is considered the general Factor of Safety – FoS. The value of FoS is calculated as the ratio of the maximum shear strength of the soil to the strength guaranteeing the balance of the slope.

3. Landslide in Tymbark

3.1. Location

The landslide analysed here has its SOPO (System Protection Against Landslides) number (8358) and it is located in the north-west part of Tymbark (Fig. 1). The Łososina river is flows on the west side of the landslide and there is a local road in the southern part. Several residential, commercial and service buildings are constructed in the vicinity of the landslide.

The landslide covers an area of about 4.5 ha. The dimensions are about 120 m in length and about 360 m in width at its base. The inclination of the slope varies from 10° to 18° in a north-western direction. The central part of the landslide is still active. The south-west part is threatened by the further soil movements.

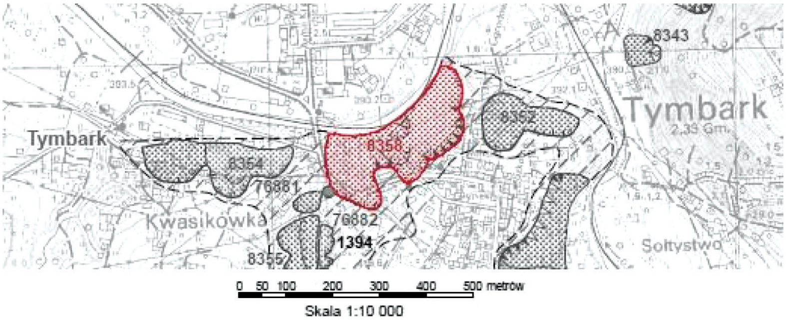

Fig. 1. Tymbark landslide location [5]

3.2. Geological structure

There are tertiary and quaternary layers here. The subsoil consists of eocene shale flysch, which is mainly slates flysch, interbedded with fine-grained sandstones and clay stones (Fig. 2).

Fig. 2. The Carpathian Flysch strata sample [2]

About 20% up to 30% of flysch layers contains the sandstones. There are quaternary, weathered layers of mainly silty clays with veined sandstones and clay stones. There are also the colluvium layers as clays, rubbles, clay stones, silty clays and clays in the bedrock. Alluvia such as pebbles, clays, and sandstones occur in the valley of the Łososina river [3].

4. Tymbark landslide stability analysis

4.1. Landslide modeling

The Tymbark landslide has been modeled using Finite Element Method (FEM) package MIDAS GTS NX (Figs. 3–4). The total number of nodes in the FEM model reached 87 904, while the number of elements is equal to 86 838. Table 1 summarizes the material characteristics of each layer of geotechnical model.

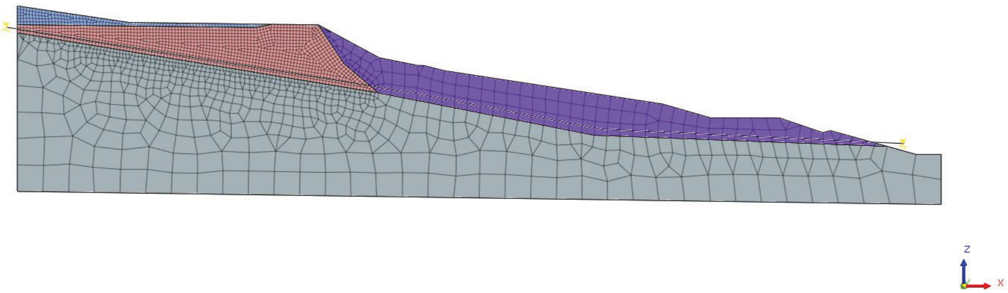

Fig. 3. Computer model of the landslide – 2D view of the mesh and soil layering. Water table level is also visible

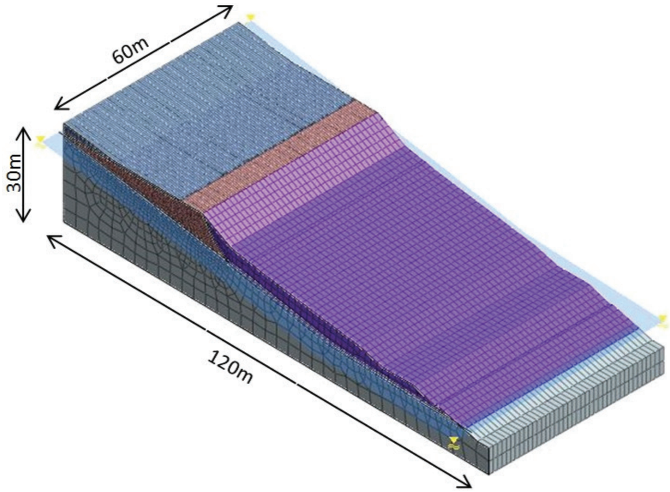

Fig. 4. Computer model of the landslide – 3D view of the mesh and soil layering and water table

Table 1. Geotechnical parameters of the layers in a calculation model

Marking	Soil symbol	Material model	Layer symbol	Poisson's ratio [–]	Water content [%]	Volumetric density [t/m³]	Cohesion [kPa]	Internal friction angle [ ]	Young modulus [kPa]
	nN	Mohr-Coulomb	**N**	0.2	16.2	2.00	10	11	25 000
	G	Mohr-Coulomb	**Ia**	0.2	18.1	2.08	10	11	40 000
	Gp	Mohr-Coulomb	**Ib**	0.2	14.5	2.25	7	10	40 000
	Iłk/PC	Mohr-Coulomb	**IV**	0.2	13.8	2.35	85	10	40 000

4.2. Loading

The slope stability is performed using the shear strength reduction method (SRM). Such a method of analysis is versatile and popular. The soil is burdened by the stress caused by the building structure located above. The existing building is 20 m in width and 40 m in length. Two cases of building foundation are considered. The first assumed the base plate foundation (Fig. 5a). It allows locate buildings of different types and in different soil conditions. The main advantage of the base plate is the ease and speed of their accomplishment. The object founded on the base plate passes self weight on the subsoil in a uniformly distributed manner. The stress acting on the ground takes the same value on the entire surface of the foundation. Stress value due to the dead weight and permanent loading is assumed equal to 28.7 kPa for the purpose of the slope stability analysis. The second case assumed the implementation of the continuous footing with a width of 100 cm for the same loading of building as in the first case (Fig. 5b). In this case, the weight of the building is transferred to the subsoil only over the width of the foundation. It has been estimated that the loading of the building is equal to 287 kN/m.

In both cases, the load is applied at a depth of the frost penetration i.e. 1.2 m below the ground level.

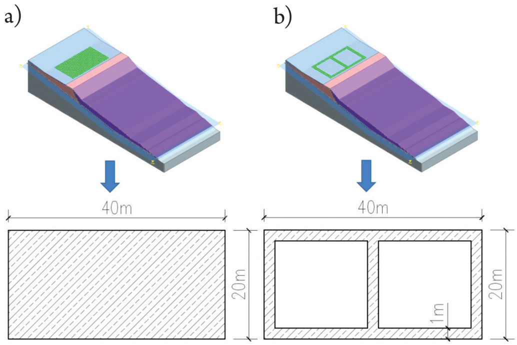

Fig. 5. Foundation: a) on the base plate, b) on the continuous footing

5. Analysis results

The aim of the calculations is to determine the maximum displacement of the slope and the location of the possible slip surface. There are also designated the maximum shear strains and maximum shear stresses of groundwater layers. Based on the obtained results, the difference between the influence of foundation on the base plate and foundation on the continuous footing has been shown. Factors of stability are also determined for analysed cases.

The minimum value of FoS based on the finite element method, using geometry of the landslide, boundary conditions and loading is determined applying the shear strength reduction method (SSR). Calculations are performed on the basis of reducing the internal friction angle and cohesion until the lack of convergence. FoS is determined at the time of loss the convergence of the calculation.

Foundations on the base plate – FoS = 1.3

The maximum displacement of the slope in both cases is approximately equal to 1.5 m (Figs. 6, 7, 10, 11). The most vulnerable to landslide movements in case where the building is founded on the base plate are shallow layers of sandy clays with crushed sandstones and shales around the building. Also in these layers the slip surface is located. In the rest of the slope, the displacement decreases to zero. These may be confirmed by the maps of maximum shear strains (Fig. 8) and maximum shear stress (Fig. 9).

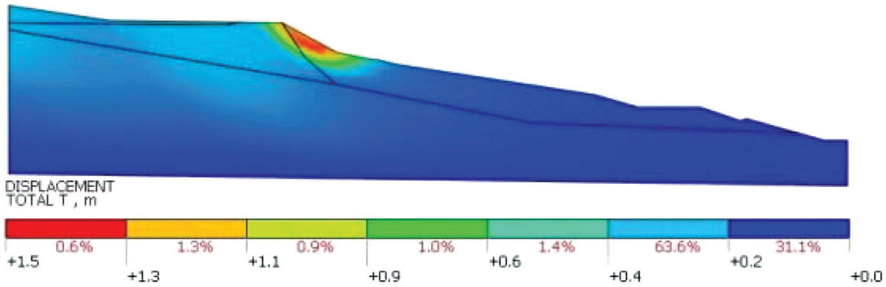

Fig. 6. Total displacement [m]

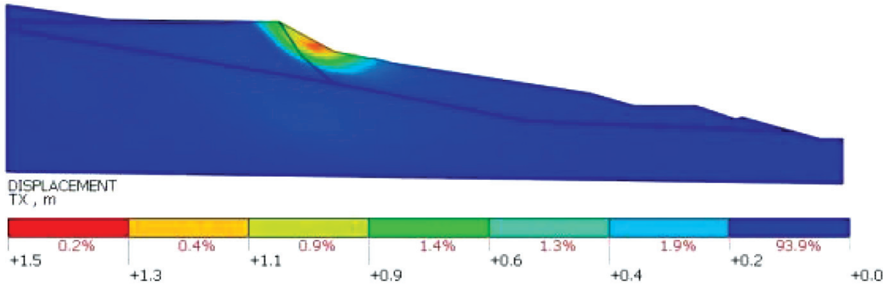

Fig. 7. Horizontal displacement [m]

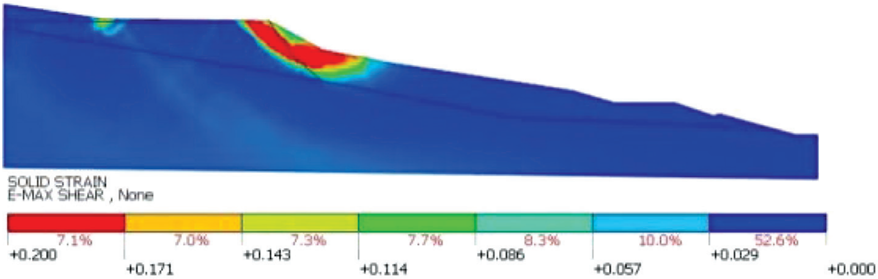

Fig. 8. Maximum shear strains [–]

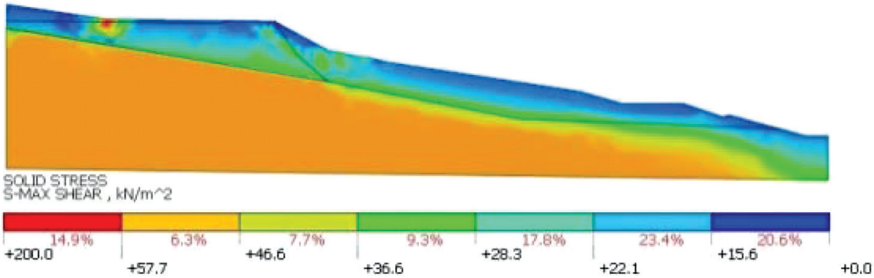

Fig. 9. Maximum shear stress [kN/m^2]

Foundations on the continuous footing – FoS = 1.1

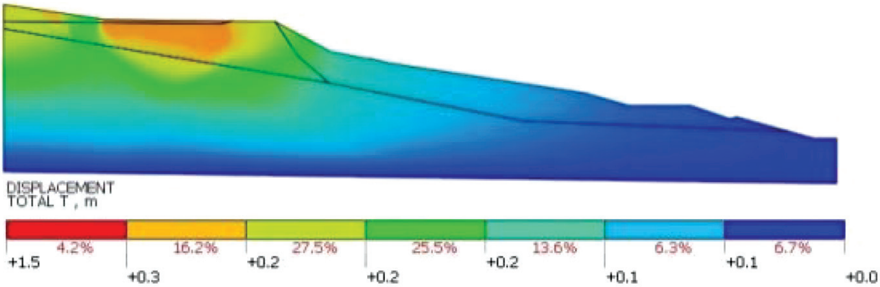

Fig. 10. Total displacement [m]

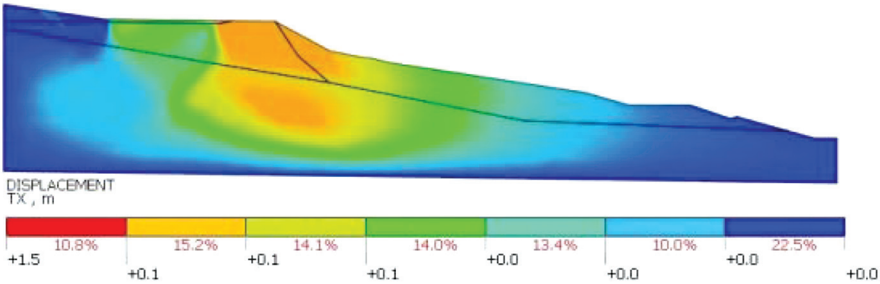

Fig. 11. Horizontal displacement [m]

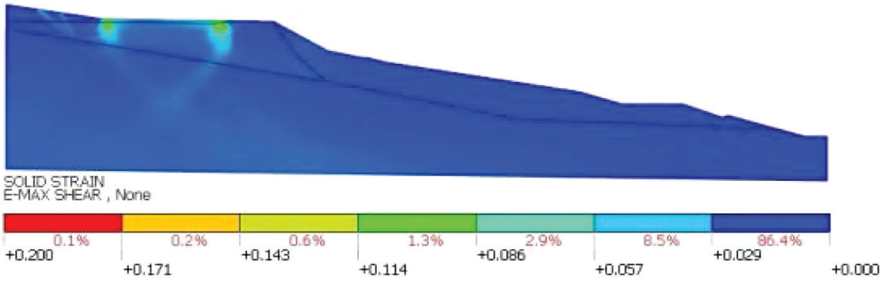

Fig. 12. Maximum shear strains [–]

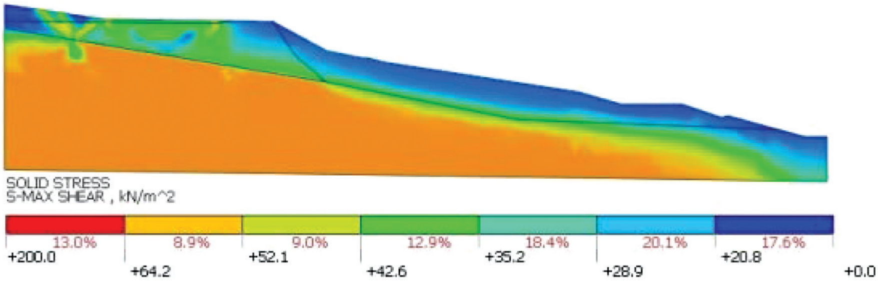

Fig. 13. Maximum shear stress [kN/m^2]

In case of the building founded on the continuous footing the maps of maximum shear strains (Fig. 12) and maximum shear stress (Fig. 13) show that all of the soil layers are at risk of landslide movements. Slip surface is located in the deeper layers of sandstone interbedded with shale.

6. Summary

The analysis of the results clearly shows that losing stability on the test landslide is very probable, regardless of the choice of the foundation method. In the first case (foundation on the base plate) FoS = 1.3. In the second case (foundation on the continuous footings) FoS = 1.1. Wysokiński [8] assumes that the occurrence of the landslide is likely if 1.0 <FoS < 1.3. Kłosiński and Lesniewski [6] relate more strictly to the built-up slopes. They built-up slope deemed stable if 1.33 < FoS < 1.43. The slope that was analysed here does not meet any of the above mentioned criteria and cannot be considered as stable.

Conclusive results based on the maximum shear strains and maximum shear stress of solid show that in case where is assumed the base plate foundation the possible slip surface appears relatively shallow – in layers of sandy clays with crushed sandstones and shales. There is also a high probability of securing such landslides, stopping further mass movements and above all, rescue building located over the potential landslide. The second method of foundation –

continuous footings could be probably much more dangerous for the building and the soil stability. The potential slip surface caused by the landslide movement, will be reached much deeper – the maximum shear stresses of the soil occur in layers of sandstone interbedded with shale. There is a serious possibility of deep, structural landslide in this case.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

CIVIL ENGINEERING

DOI: 10.4467/2353737XCT.17.176.7284

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An environmental life-cycle assessment of selected concrete recycling processes

Ocena środowiskowa wybranych procesów recyklingu betonu

Abstract

Social and economic development trends require that the economy be based on sustainable consumption and sustainable production patterns by means of implementing an effective recirculation policy – this is also important from an environmental perspective. Consequently, the design of economic processes becomes increasingly complex. This paper presents method and results of environmental life-cycle assessment of selected stages of the concrete recycling process. The results will be used in a further, holistic assessment of managing the concrete waste on the construction site.

Keywords: LCA, RCA, sustainable construction

Streszczenie

Społeczno-gospodarcze trendy rozwojowe, wymagają aby gospodarka oparta była na zrównoważonej konsumpcji oraz zrównoważonych wzorcach produkcyjnych, poprzez prowadzenie efektywnej gospodarki recyrkulacyjnej – również w wymiarze środowiskowym. Dlatego też, projektowanie procesów gospodarczych przyjmuje coraz to bardziej złożony charakter. Artykuł prezentuje metodę i wyniki oceny środowiskowej wybranych etapów procesu recyklingu betonu. Rezultaty posłużą do dalszej – holistycznej oceny wariantów gospodarowania odpadami betonowymi na budowie.

Słowa kluczowe: ocena środowiskowa, kruszywo z recyklingu betonu, zrównoważone budownictwo

1. Introduction

The transformation of current production and consumption methods requires adopting a circular economy paradigm which in practice means the implementation of return chains – this is based on the logistics of recycling and the closing of the classical (linear) supply chain [4].

The circular economy concept has already been successfully implemented in many industries, including within the construction industry; the next challenge is to improve the effectiveness of the economic processes [2]. Regarding effectiveness, one should remember the triad of sustainable development – economic, environmental and social aspects. Consequently, the production processes should be designed and optimised based on a multi-criterion analysis which includes an environmental assessment [9]. The goal of the paper is to identify the scale of environmental effects of the concrete recycling process at a construction site and to determine the significant variables and parameters for unit processes – this was achieved by conducting a case study. The description of the assessment methodology forms an extensive part of the paper. In the studied case, the assessment results provided a clear indication as to the organisation of the recycling processes which have the least environmental impact.

2. Research methodology

The research methodology is based on a classical systemic approach using the LCA method [1, 5]. The concrete recycling system was separated and divided into unit processes which are interconnected and connected with surroundings via the input and output values. Thus, the assessment of the environmental impact of recycling is a summary assessment of the impact of individual unit processes. The assessment is consequently a 'gate-to-gate' type. The assessment was made using the *GaBi* software from *Thinkstep* which contains comprehensive *GaBi* databases with worldwide coverage as well as *Ecoinvent* data [7].

2.1. Goal and scope of assessment

The goal of the investigation was to perform a comparative analysis of the environmental effects of concrete recycling processes for various sets of machines. The assessment was simplified (it was based on average values, the main source of data was the literature); nonetheless, by analysing varied parameters, it enabled the identification of key decision variables and parameters which significantly determine the environmental impact of the process. The scope was limited to (and focuses exclusively on) the assessment of the recycling processes carried out directly on site using mobile jaw crushers. There were four unit processes within the system boundaries – preparatory operations, principal operations, accompanying operations, and final operations, these are graphically presented in Fig. 1.

It was assumed that the processing of debris would result in obtaining a 0–63 mm ungraded aggregate. The assessment was made for four crusher types with varying parameters (Table 1)

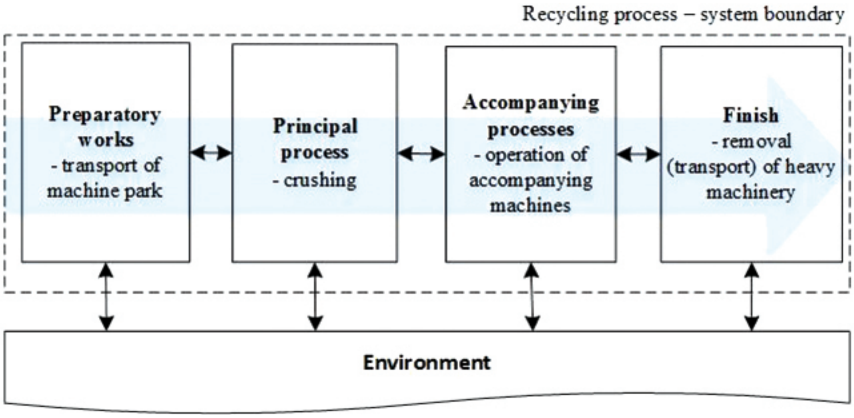

Fig. 1. Concrete recycling system with mobile machinery

for the following boundary conditions: crusher transport distance 200 km; amount of debris to be recycled 100 Mg. The analysis enabled the identification of the most advantageous solution for the studied case.

Table 1. Parameters of assessed crushers

Variant (crusher)	Crusher weight [kg]	Average crushing capacity [Mg/h]	Engine power rating [kW]	Standard
K1	1,400	10	10.8	Stage III A
K2	2,900	17.5	29.6	Stage III A
K3	10,000	40	52.0	Tier IV
K4	27,800	125	168	Stage III A

The recycling process starts with setting up the on-site recycling process line which entails the transport of machines – a crusher and, if not already present on site, an excavator/loader (in the studied case, there was already an excavator on site). The next assessed stage is the principal process – concrete crushing. The remaining components of the process which require assessment are the operation of the excavator which loads the debris and the finishing processes, i.e. removal of machine (crusher only) from the site.

2.2. Life-cycle inventory

The analysis of input and output set was performed on data from literature and was supported by the *GaBi* database. Table 2 presents the sources of input and output data relating to the transport unit processes for various types of crushers to and from the site (preparatory and finishing processes).

In the accepted transport model, the input values for unit processes are diesel and cargo (crusher). The outputs are cargo (crusher) and combustion emissions such as ammonia, benzene, carbon dioxide, carbon monoxide, methane, nitrogen monoxide, nitrogen dioxide, nitrous oxide, NMVOC, particulate PM 2.5, sulphur dioxide etc. Truck production, end-of-life treatment of the truck and the fuel supply chain are not included in the data set.

Table 2. Parameters for assessment of crusher transport

Variant:	Crusher 1	Crusher 2	Crusher 3	Crusher 4
Database	diesel driven, Euro 3, cargo;			
	up to 3.3t p.c.*		up to 11.4t p.c.	up to 27**t p.c.
Common parameters:	Distance: 200 [km]. driving share: 0.5 motorway, 0.33 rural, 0.07 urban. Other: default			
Individual parameter – payload:	1.4 [t]	2.9 [t]	10 [t]	27 [t]

**p.c.-payload capacity; **no data for larger payload.*

The sets of inputs and outputs were determined based on the literature data, including the valid stage and tier emission standards for diesel engines [6] and assuming limit of emissions (s_n). Emissions from the engine (output) and average fuel consumption (input) per megagram of produced concrete aggregate are given in Table 3.

Table 3. Parameters for assessment of crushing process

Variant	Emissions to atmosphere [g/Mg]			CO_2 [kg/l]	Fuel consumption [l/Mg]
	CO	$HC+NO_X$	PM		
Crusher 1	7.13	8.1	0.43	3.2 kg	0.2
Crusher 2	9.3	12.69	1.01		0.29
Crusher 3	6.93	6.52	0.55		0.27
Crusher 4	4.7	5.38	0.27		0.16

Furthermore, the crushing process results also in emissions of PM and PM10 dust from the process of the mechanical grinding of concrete. In the case of crushing dry material with jaw crushers, the average emissions are [8]: PM – 0.32 [g/Mg]; PM10 – 0.15 [g/Mg]. For crushing wet material, the average emissions are: PM – 0.16 [g/Mg]; PM10 – 0.07 [g/Mg].

The input data for the excavator operation model includes diesel and excavated material. Outputs are combustion emissions due to engine operation and are comprised of regulated emissions (NOx, CO, Hydrocarbons and Particles), fuel-dependent emissions (CO_2, SO_2, benzene, toluene and xylene) and others such as CH_4 and N_2O. Emissions due to machinery production, end of life, and the fuel supply chain was excluded. The parameters of selected excavator operation variants are given in Table 4.

In the case of all unit processes, the environmental load from fuel consumption was calculated using the database, *EU-27 Diesel mix at refinery*.

All the used items of data are highly comparable in terms of time and geography. As far as completeness of *input* and *output* data was assured, only the crushing processes are unverified – these are partially based on assumptions. The major part of the *inputs* and *outputs* set is based on data from literature (68.7%) and on calculations (26.4%).

Table 4. Parameters for the assessment of excavator operation

Variant		Loading 1	Loading 2	Loading 3	Loading 4
Database		Excavator, 100 kW, construction*			
Common parameters:		Material bulk density: 1.8 [t/m³] Fuel consumption (operating): 10 [kg/h] Other: default			
Individual parameters	Bucket capacity [m³] :	0.3	0.5	1.1	2
	Load factor [–]:	0.3	0.4	0.6	0.9
	cycles_min [1/min]:	0.3	0.32	0.4	0.57

* Due to the presence of the excavator on site, the same model was used for different variants

3. Results

The recycling processes were assessed using the ILCD methodology, recommended by the Joint Research Centre (JRC). More information about the selected method can be found in [3]. The set of results only shows selected environmental impact indicators: GWP (Fig. 2),

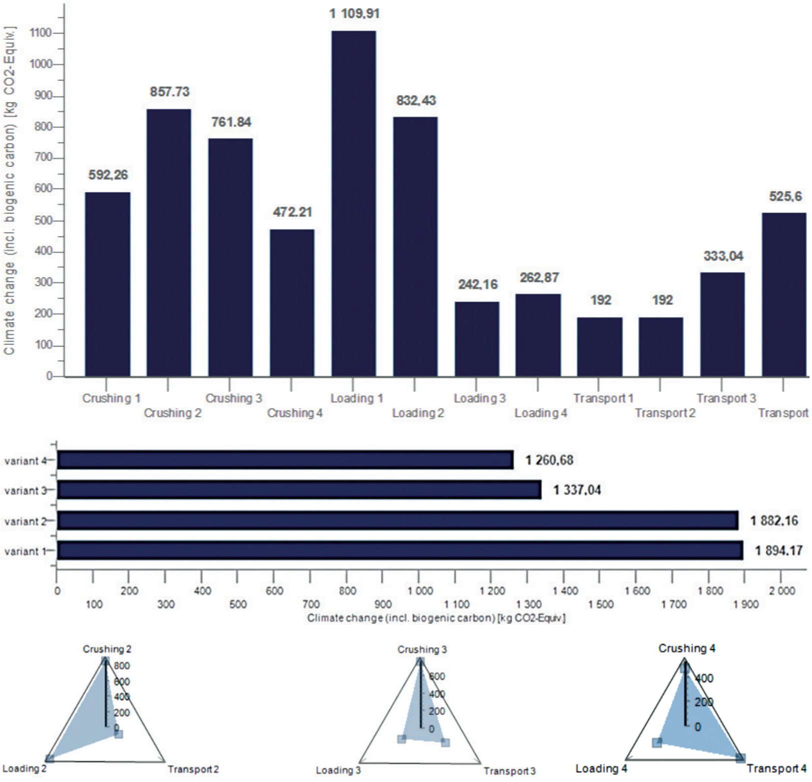

Fig. 2. Global warming potential (GWP): a) for unit processes, b) for individual variants, c) variation of unit processes in selected variants

particulate matter (Fig. 3) and POCP (Fig. 4) – for all unit processes and the impacting factors for individual variants. In the model, the efficiency and power of the excavator is constant – this approach has facilitated inference about the variable capacity of the crusher and has led to interesting conclusions.

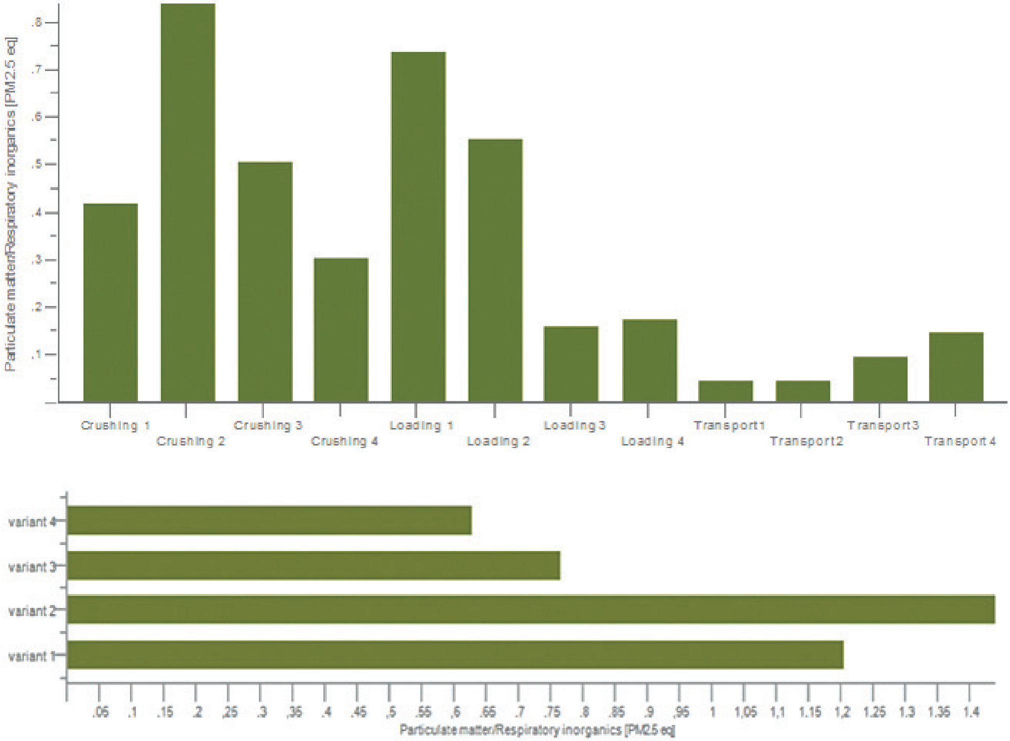

Fig. 3. Particulate matter: a) for unit processes, b) for individual variants

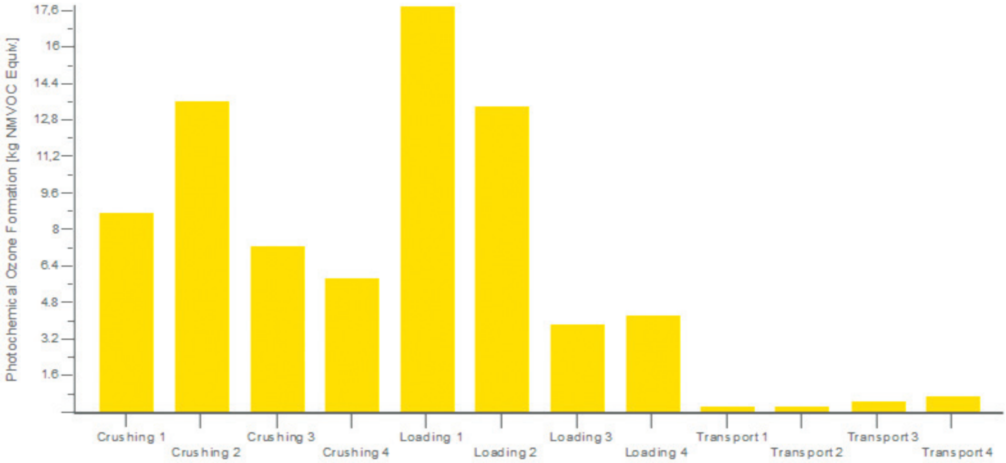

Fig. 4. Photochemical ozone creation potentials (POCP) for unit processes

Adopting a powerful excavator model and equipping it with low-capacity crushers (variants 1 & 2) causes the entire system to become environmentally inefficient – attention is drawn to the intensification of the companion process *loading 1* and *loading 2* (GWP: 1109.91 and 832.43 kg CO2-eq.), which cannot be compensated even by the transport process (for a given distance, GWP: 192 kg CO2-eq).

The most advantageous solution for the given conditions is option 4, the use of machines of relatively high efficiency and large dimensions, even with the intensification of the transport process for this variant (GWP: 525.6 kg CO2-eq). This is due not only to the high efficiency of the operation of the crusher (the lowest GWP, PM, POCP) but also effective cooperation with the excavator. Due to the individual parameters of the model, the results are not comparable with data from the literature.

4. Summary and conclusions

The recycling of concrete using the described technology has an impact on the environment, particularly contributing to global warming, emissions of particulate matter, and the creation of photochemical smog. The burning of fuel to power the construction machines and transport vehicles constitutes a significant share of the carbon dioxide emissions. It is not possible to explicitly indicate the process in the entire recycling process which has the largest environmental impact – this is evidenced by the varied load level of the unit processes in the different variants (Fig. 2c). Furthermore, the environmental loads of the unit processes and their share in individual variants were indeed dependent upon numerous parameters – distance to transport equipment, amount of debris, relationship between fuel consumption and the effectiveness of the crushing process, engine class, road quality, etc. – these relationships will be studied in further analyses.

The result of the environmental assessment of the excavator and loader operation is interesting. Effectiveness does not depend on the productivity of individual machines but on their effective cooperation. The oversized excavator in variants 1 and 2 made the whole system environmentally ineffective. This example confirms the importance of the correct selection of accompanying machines to the principal process not only because of the economic effectiveness – this relationship is generally known – but also in relation to the environmental issues.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

MECHANICS

DOI: 10.4467/2353737XCT.17.178.7286

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Empirical research of human-weapon system

Badania empiryczne układu człowiek-broń

Abstract

Rapid firing of the Skorpion vz.61 machine gun was registered at a police shooting range. The shooting was executed by a policeman from the secret service. The registration was done with the use of a fast digital camera Phantom v9.1 together with the necessary equipment. With the use of the specialised TEMA software, which serves to analyse the recorded image, the courses of the variation of kinematic quantities characterizing the weapon movement were obtained. On the basis of the courses of the variation of the displacement, velocity and acceleration over time, the behaviour of the machine gun in thirteen characteristic points of its operation was specified.

Keywords: weapon, human, registration of firing, kinematics of movement

Streszczenie

Na strzelnicy policyjnej została przeprowadzona rejestracja strzelania ogniem seryjnym z pistoletu maszynowego Skorpion wz.61. Strzały oddane zostały przez policjanta ze służb specjalnych. Rejestrację przeprowadzono przy wykorzystaniu szybkiej kamery cyfrowej wraz z niezbędnym oprzyrządowaniem. Przy wykorzystaniu specjalistycznego programu TEMA, służącego do przeprowadzania analizy zarejestrowanego obrazu, uzyskano przebiegi zmienności wielkości kinematycznych charakteryzujących ruch broni. Na podstawie otrzymanych przebiegów zmienności przemieszczenia, prędkości i przyspieszenia w funkcji czasu określono zachowanie się pistoletu maszynowego w trzynastu charakterystycznych punktach jego działania.

Słowa kluczowe: broń, człowiek, rejestracja procesu strzelania, kinematyka ruchu

1. Introduction

The subject of the research is the Skorpion submachine gun, vz.61, cal. 7.65 mm, as shown in Figure 1. An engineer – Miroslav Rybar from Zbrojovka Brno – started constructing it in 1958. The gun is therefore not the latest design. Its use presented a fairly large dispersion of the bullets fired, especially when shooting from a distance exceeding 25 m. Special units of the army and police are equipped with this type of weapon. The Skorpion submachine gun constitutes only an example of automatic weapons on the basis of which a comprehensive analysis intended to improve its effectiveness will be conducted. Ultimately, the task of the considerations undertaken is to develop guidelines with the aim to shape the dynamic properties of automatic weapons, in order to reduce the dispersion of rapidly fired bullets.

In this paper, the preliminary elements of experimental research are presented, which aim to define the kinematics of the movement of the human-weapon system. With the use of the specialised TEMA software, which serves to analyse the recorded image, the courses of the variation of kinematic quantities characterizing the movement of two weapon points were obtained. On the basis of the courses of the variation of the displacement, velocity and acceleration over time, the behaviour of the machine gun in thirteen characteristic points of its operation was specified.

2. Operation of the Skorpion submachine gun

Operation of the Skorpion submachine gun is based on the principle of blowback recoil [1]. The lock is supported by two resistance-return springs. A single or rapid firing is performed with the lock closed. The lock moves in the receiver of a rectangular cross-section that was extruded from a steel plate. The so-called "clips", which serve to tension the lock, move in the extrusions along its both sides. The extractor slot is located at the top of the receiver. Through the slot, the used shells are discharged vertically upwards.

Before loading the cartridge, the lock is located in the front extreme position. Due to the force generated by the resistance-return springs, the lock is pressed against the rear end of the barrel and thus, it locks the barrel with the receiver. The hammer is released and its working surface leans against the rear end of the firing pin.

In order to prepare the machine gun for fire, a loaded magazine needs to be strapped. Then, we release the weapon and vigorously move the lock to the rear most position. The retreating lock turns the hammer, which meshes with the catch. After releasing the lock, the compressed springs of the return device move it forward.

The returning lock hits the cartridge that partially protrudes from the magazine and redirects it to the receiver. At that time, the extractor claw that is supported with the spring moves behind the orifice in the shell. The lock, which is pressed with the springs of the return device against the rear end of the barrel, locks the receiver. After pressing the trigger, the hammer that is released from the catch with the use of the power generated by his spring, turns around and hits the end of the firing pin that protrudes from the lock. The firing pin hits the shell with its stricker and a shot is fired.

The pressure of the burnt gases pushes the bullet from the barrel and operates with the same force on the bottom of the shell. By operating on the bottom of the shell, the energy of expanded gases unlocks the receiver and reverses the lock. The shell that moves together with the lock goes to the extractor and is ejected through the extractor slot. The lock turns the hammer again, which compresses his spring. With the setting on continuous fire, the hammer meshes with the catch of the automatic trigger and the hammer catch.

When the retreating lock passes the magazine, the magazine follower using the spring located in the magazine raises another cartridge until it leans against the magazine jaws. The compressed springs of the return device move the lock forward. Then, the lock selects the next cartridge from the magazine and directs it into the receiver. In the final phase, the returning lock, which impacts the lever of the automatic trigger, releases the lock from the automatic catch and after locking the receiver, another shot is fired. The procedure is repeated until the last shot has been fired or the pressure on the trigger has been released. In both cases, the hammer meshes with the hammer catch and firing of subsequent bullets is interrupted.

When the fire selector switch is set to single fire, the lock operates similarly as previously, except that this time, the hammer meshes immediately with the hammer catch and firing of subsequent bullets is interrupted.

3. Experimental research

3.1. Characteristic phases of weapon operation

Firing the Skorpion vz.61 machine gun equipped with a silencer was registered at the police shooting range. The shots were fired by a policeman from the secret service. The registration was executed with the use of a fast digital camera Phantom v9.1 together with the necessary equipment. A sample picture presenting the shooter holding the weapon while firing two shots – the so-called rapid fire, i.e. consecutive shots at regular intervals specified by the operation of mechanisms of the machine gun, is shown in Fig. 2. When the second bullet leaves the barrel, the shell that was thrown out by the first cartridge is found at the height of the policeman's helmet, making a spherical movement along a curved trajectory.

Two tags – respectively point 1 and point 2, as in Figure 1 – were placed on the silencer and the receiver. With the use of the specialised TEMA software, which serves to analyse the recorded image, the courses of the variation of kinematic quantities characterizing the movement of two chosen points were obtained. In order to perform unambiguous considerations, a coordinate system connected to the Earth was introduced. In the case of the object in question, it might be assumed that this is the topocentric system of Galileo. The beginning of this coordinate system at the start of registration coincides with point 2, the axis 0x is directed from point 2 to point 1, the axis 0y is directed vertically upwards and coincides with the direction of operation of the field of gravitational forces and the axis 0z is an addition to the orthogonal clockwise Cartesian

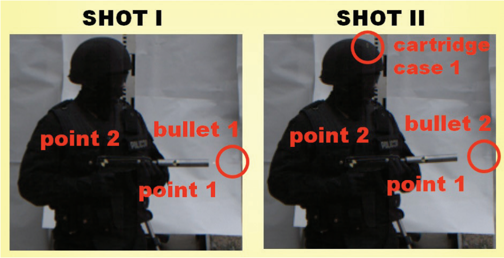

Fig. 1. A police officer while firing two shots from the Skorpion submachine gun

system of reference. Figures from 5 to 19 present the courses of the variation of the coordinates of displacement, velocity and linear acceleration – point 1 and point 2 and angle, angular velocity and angular acceleration in the movement of weapon tilt over time.

The analysis of the graphs was conducted with thirteen characteristic points of operation of the weapon taken into consideration:

a) The first shot – I (Fig. 2):
   1) $t = 0.0448$ [s] – lock movement to the rear position
   2) $t = 0.0462$ [s] – cartridge bullet 1 leaves the barrel
   3) $t = 0.0532$ [s] – cartridge shell 1 is thrown out of the receiver
   4) $t = 0.0581$ [s] – lock reached the extreme rear position
   5) $t = 0.0749$ [s] – lock movement to the front position
   6) $t = 0.0973$ [s] – lock reached the extreme front position

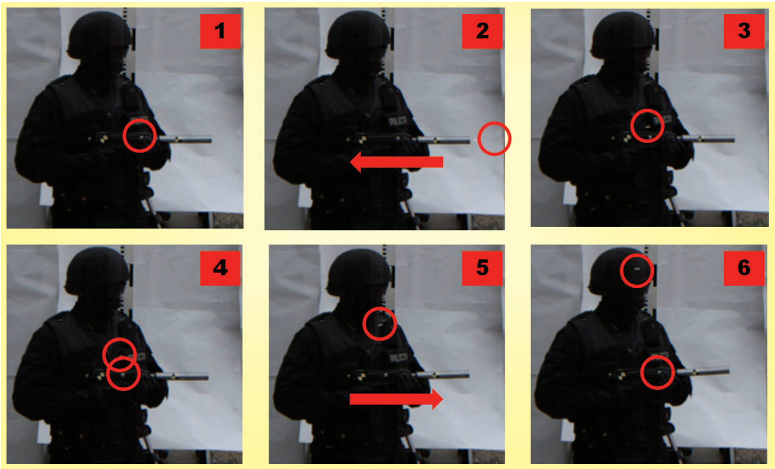

Fig. 2. Characteristic moments of time while firing the first shot

b) The second shot – II (Fig. 3):
   7) $t = 0.1022$ [s] – lock movement to the rear position
   8) $t = 0.1036$ [s] – cartridge bullet 2 leaves the barrel
   9) $t = 0.1134$ [s] – cartridge case 2 is thrown out of the receiver

10) $t = 0.1162$ [s] – lock reached the extreme rear position
11) $t = 0.1484$ [s] – lock movement to the front position
12) $t = 0.1743$ [s] – lock reached the extreme front position

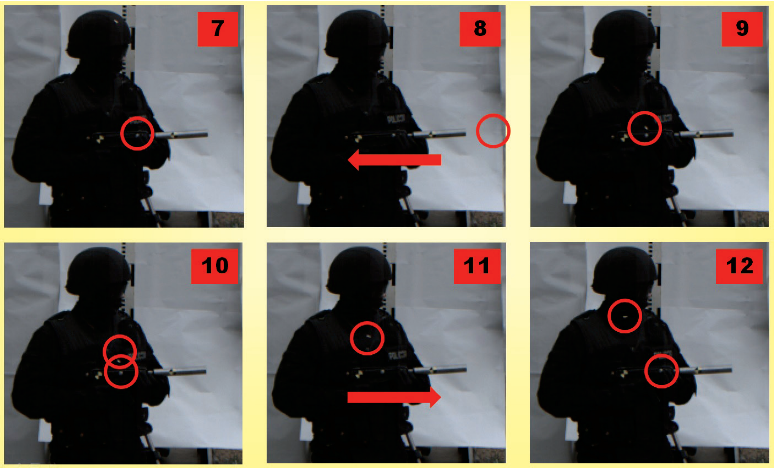

Fig. 3. Characteristic moments of time while firing the second shot

c) The shooter leaves the weapon
13) $t = 0.2604$ [s] – the end of the observation

3.2. The course of the variation of kinematic quantities characterising the movement – point 1

Figures from 4 to 6 show the courses of the variation of kinematic quantities over time characterizing the movement – point 1 in the direction of the axis 0x. Figures from 7 to 9 present the courses of the variation of kinematic quantities over time characterizing the movement – point 1 in the direction of the axis 0y. The points indicating specific moments of the time of the weapon operation are plotted onto the graphs.

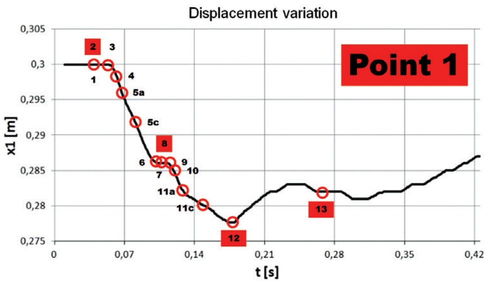

Fig. 4. Displacement of point 1 in the direction of the axis 0x

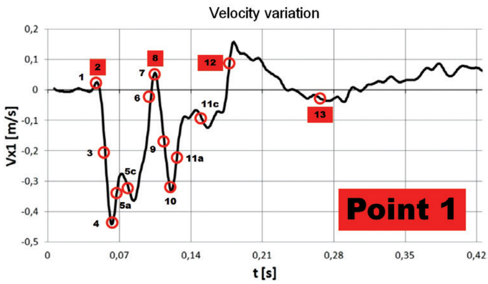

Fig. 5. Velocity of point 1 in the direction of the axis 0x

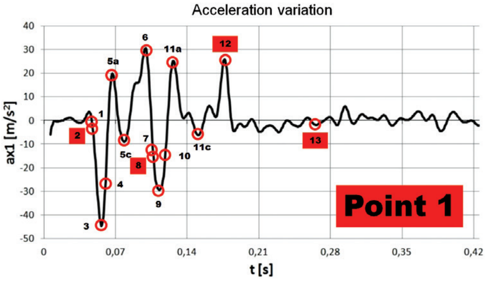

Fig. 6. Acceleration of point 1 in the direction of the axis 0x

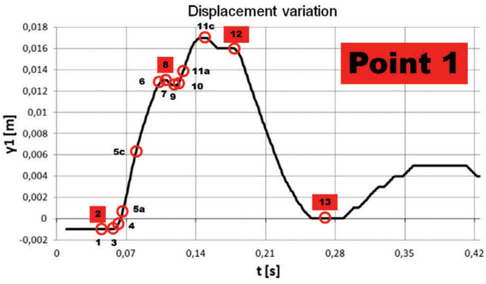

Fig. 7. Displacement of point 1 in the direction of the axis 0y

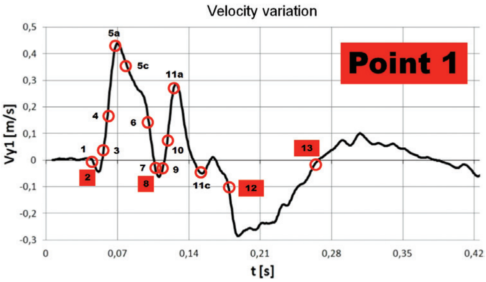

Fig. 8. Velocity of point 1 in the direction of the axis 0y

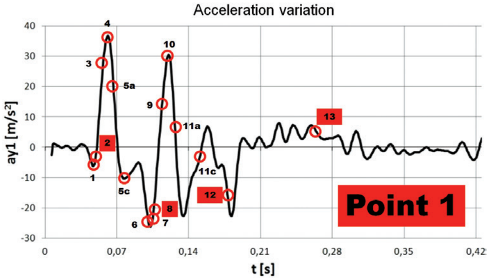

Fig. 9. Acceleration of point 1 in the direction of the axis 0y

3.3. The course of the variation of kinematic quantities characterising the movement – point 2

As a result of the analysis of the images that were obtained during registration at the shooting range, it might be assumed that all points of the submachine gun move along planes that are parallel to a certain fixed vertical plane. Therefore, the research is limited to the movement of a flat figure. The location of such figure at any point in time is unequivocally defined by the position of the section. For this purpose, it is necessary to determine the position of not only point 1, but also point 2.

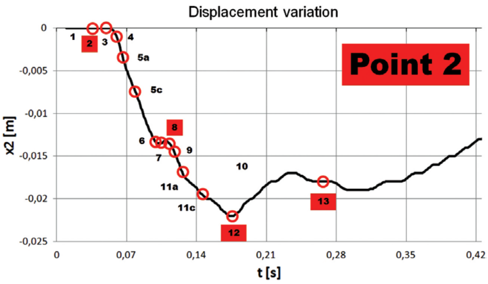

Fig. 10. Displacement of point 2 in the direction of the axis 0x

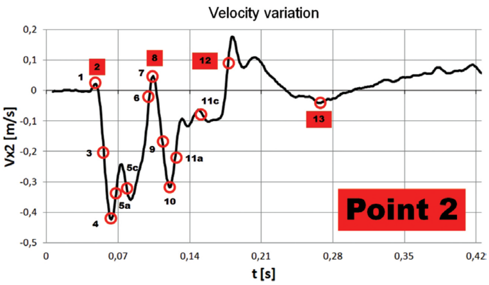

Fig. 11. Velocity of point 2 in the direction of the axis 0x

Figures from 10 to 12 present the courses of the variation of kinematic quantities over time characterizing the movement of point 2 in the direction of the axis 0x. Figures from 13 to 15 show the course of the variation of kinematic quantities over time characterizing the movement of point 2 in the direction of the axis 0y. The points indicating specific moments of the time of the weapon operation are plotted onto the graphs.

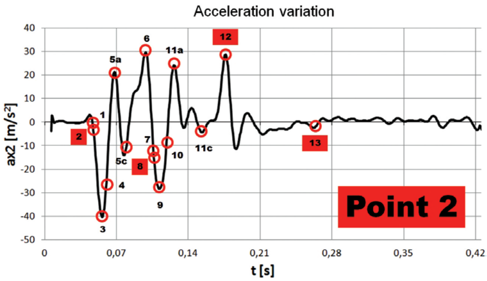

Fig. 12. Acceleration of point 2 in the direction of the axis 0x

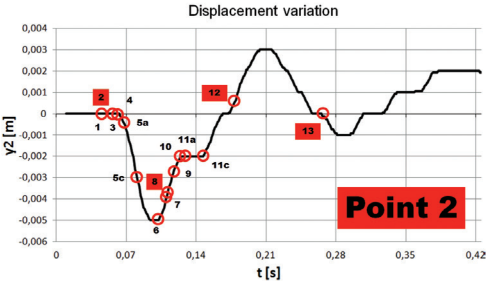

Fig. 13. Displacement of point 2 in the direction of the axis 0y

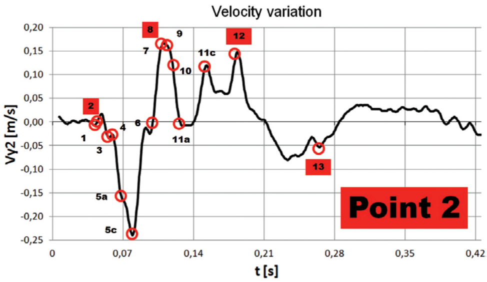

Fig. 14. Velocity of point 2 in the direction of the axis 0y

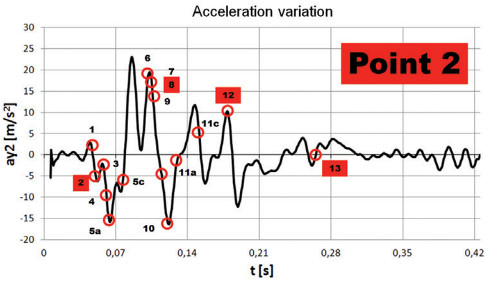

Fig. 15. Acceleration of point 2 in the direction of the axis 0y

4. Elements of biomechanics of the shooter

A human being is a complex biological system. Its functioning is determined by the current psychophysical state. The fluctuation of the behaviour and the biological features of an individual as well as the wide range of potential people that could use a weapon does not facilitate the research. A unification of the human body is impossible. As far as the biomechanical issue related to a human being is concerned, the spine plays a very important role [2, 3, 7]. It constitutes the central axis of the human body. The main function thereof i.a. is to support and carry the upper body part. It is also the place where bones and muscles related to proper functioning of limbs are attached. Due to its construction, the spine is both strong and very flexible. Its strength depends on the time of load. A too short time of increasing the load does not allow all damping mechanisms to start operating. Such a phenomenon occurs when firing a machine gun. Through the system of shoulder girdle, the spinal load is transmitted to the upper extremities, causing a disorder of precise movements [9]. Through the vertebrobasilar connector, vibrations are also transmitted to the head. This can cause significant disturbances of sight fixation and an impairment of visual acuity. In the case of large and sudden loads, displacements of brain structures in a rigid bone box, i.e. the skull, might occur. In such conditions, blood flow through the brain and retina may also be prone to some disturbances. All these phenomena may negatively affect the behaviour of the shooter when shooting personal guns.

5. Summary

Rapid firing of two bullets from the Skorpion vz.61 machine gun was registered at the police shooting range with the use of a fast digital camera Phantom v9.1. The tests confirmed the opinion of the users regarding the presence of large dispersion. An acceptable dispersion between two bullet holes should not exceed 0.5 [m] when shooting at the target located at a distance of 25 [m]. Such an assumption stems from the needs of using the weapons, among others, by anti-terrorists who must render the enemy powerless without causing casualties among outsiders. Currently, the dispersion of the gun fluctuates within 1.3 [m]. Due to the popularity of weapons, the results obtained encouraged the authors to strive to improve its accuracy [4].

This paper presents the elements of experimental studies based on the analysis of the recorded images. The application of standard software as well as the specialized TEMA software allowed to carry out the qualitative and quantitative considerations. During firing, many physical phenomena determine the final effect in the form of weapon accuracy. In this study, the authors focused on research that aimed at defining the kinematics of the movement of the human-weapon system. For this purpose, the courses of the variation of kinematic quantities characterizing the movement of the machine gun were specified. The courses of the variation of displacement, velocity and acceleration over time were obtained, which allowed to determine the behaviour of the machine gun in thirteen characteristic points of its operation [11].

A human being is a complex biological system. In particular, the osteo-muscular system and the nervous system have an impact on human motor activities [8]. Human reaction to the phenomenon of recoil when firing depends on many factors [5]. One of them is the experience of the shooter. In this case, the shooter is a very well-trained policeman from the secret service. The results of experimental studies prove a clear movement of the gun both in the linear and the angular direction. Each of the bullets fired after leaving the barrel performs a different trajectory [6.12]. This is a result of different initial conditions, which are formed while leaving the barrel by the bullet. This leads to unsatisfactory accuracy [4].

Further discussion will aim to use the empirical results to develop a theoretical model taking the relevant physical phenomena and processes into account. Theoretical analysis and motion simulation in virtual space will enable to conduct a thorough study of the dynamics of human-weapon system [10]. The authors strive in their studies to develop guidelines that allow a correction of the dynamic properties of an automatic weapon, and thus, increase its accuracy.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

MECHANICS

DOI: 10.4467/2353737XCT.17.179.7287

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Matrix FMEA analysis with cause-effect diagram for selected fluid power component

Macierzowa analiza FMEA z wykorzystaniem diagramu przyczynowo-skutkowego wybranego elementu hydrauliki siłowej

Abstract

This paper presents an application of matrix FMEA analysis and cause-effect diagram for a double acting hydraulic cylinder. A decomposition of the investigated cylinder has been made and main functions and potential failures for the pair-function relation have been identified. Elements with the greatest probability of failure and cause-effect relationship have been determined.

Keywords: FMEA, cause and effect diagram

Streszczenie

W artykule przedstawiono macierzową analizę FMEA siłownika hydraulicznego dwustronnego działania. Dokonano dekompozycji, zidentyfikowano podstawowe funkcje i potencjalne wady dla relacji para–funkcja. Określono elementy, które charakteryzują się największym prawdopodobieństwem wystąpienia wad i wyznaczono związki przyczynowo-skutkowe.

Słowa kluczowe: FMEA, diagram przyczynowo-skutkowy, hydraulika

1. Introduction

Hydraulic power systems are widely used in many applications due to their versatility and possibility of power transmission. However, more and more demands are put on hydraulic systems to ensure their reliability in extreme environmental conditions. Therefore, the ability of identifying potential defects during the design and manufacturing processes has a great importance. More than a half of all defects arise during the design and manufacturing, but they are detected mostly during operation. Therefore, new methods, tools and techniques that can be used for the assessment of product quality at the design and manufacturing stage have been developed in the last years. Qualitative methods, among which the FMEA (Failure Mode and Effects Analysis) can be distinguished, are examples of such methods. The FMEA is used to identify potential faults and their causes that may arise during the design and manufacturing processes [1]. The method allows for the qualitative assessment of reliability in order to evaluate the risks and consequences of any defects that may have occurred. Because of the possibilities of identification of potential defects at the early stages and relatively simple integration with computer aided and expert systems, the FMEA seems to be an effective tool which may have a great impact on the quality and reliability of hydraulic power systems.

2. The FMEA principles

The FMEA was developed in 1949 for the needs of the US Army and has been described in MIL-P1629 standard "Procedures for Performing a Failure Mode, Effects and Criticality Analysis". The aim of application of this method was the evaluation of the degree of risk of military missions, taking into account command systems, equipment and human resources. Currently, the FMEA is used wherever the product/process, for reasons of people's safety and the environment, is required to meet the "zero defects" principle. Therefore, the FMEA includes not only the manufacturers of final products, but also suppliers, for whom the use of this method is a condition of establishing cooperation. The FMEA procedure is included in the ISO/TS 16949 specification, which integrates qualitative systems in the automotive industry and in EN 60812: 2006 (U) "Analysis techniques for system reliability. Procedure for failure mode and effects analysis (FMEA)" standard as well. The FMEA method which depends on the way potential defects are identified and presented may be divided into classical and matrix methods. Classical FMEA evaluates the Risk Priority Number (RPN), while matrix FMEA determines the function-failure relationship. The matrix FMEA (xFMEA) shows the relationship between investigated components, their functions and identified failures.

3. The xFMEA analysis of hydraulic cylinder

Matrix FMEA analysis was conducted for a typical double acting hydraulic cylinder which is widely used in hydraulic drive systems. The analysis was conducted at three stages. The first one was a decomposition of a hydraulic cylinder structure, identification of the basic functions of components and identification of potential defects. The second stage was to determine three diagrams of dependence. The EP matrix shows the relationship between the pairs of cooperating components (P) and their functions (E). The PF matrix is the relationship between failures (F) and pairs (P). The dependencies were described using a binary evaluation system. The value of 0 is assigned if there is no dependence, while value 1 if a dependency exists. The third matrix (EF) is a function – potential failures relation, which arose as a result of the multiplication of (EP) and (PF) matrixes.

The investigated hydraulic cylinder consists of a cylinder with its bottom and a nut. The cylinder has a piston with a seal and gland. The piston is connected to a self-aligned bearing by the piston rod. There is a wiper ring, two guiding rings and three sealing rings in the gland. The cylinder and its bottom were considered as one component. The piston sealing system was considered as one sealing set. Finally, the FMEA analysis included a cylinder (c1), piston (c2), piston rod (c3), gland (c4), cap (c5), sealing system (c6) and a self-aligned bearing (c7). Subsequently, eleven pairs of cooperating components were determined (p): p1 (c1, c2), p2 (c1, c6), p3 (c1, c4), p4 (c1, c5), p5 (c2, c3), p6 (c2, c6), p7 (c3, c6), p8 (c3, c4), p9 (c3, c7), p10 (c4, c6), p11 (c4, c5). Each pair has an individual function in the cylinder (EP matrix). Four functions have been found:

- fixing (e1): ensures correct position of the components and their alignment: p1, p4, p9, p11,
- converting (e2): energy conversion of working fluid pressure into mechanical energy, energy transfer: p5,
- preventing (e3): prevents against dust, dirt, grains of sand; removes contaminations: p7, p10,
- protecting (e4): secures leakage of hydraulic fluid, sealing the piston and the piston rod, absorbs mechanical vibrations and side load: p2, p3, p6, p7, p8, p10.

In the next step on the basis of available references [2, 3, 8] and identified functions, ten potential failures were determined, which were classified into 5 categories in a similarity matrix. Those are: wear (f1), corrosion (f2), seizure (f3), fatigue (f4) and buckling (f5). In Table 1 each failure (f) a pair (p) in which failure may occur was assigned (PF matrix).

Table 1. Similarities matrix for identified failures for investigated components

Potential failure	Type of failures (f)	Pair (p)
abrasive wear, adhesive wear	wear (f1)	p1, p2, p3, p4, p5, p6, p7, p8, p9, p10, p11
oxidation wear, pitting		
crevice corrosion, fretting corrosion	corrosion (f2)	p1, p4, p5, p7, p8, p9, p10, p11
seizure	seizure (f3)	p1, p2, p3, p6, p7, p8, p10, p11
fatigue friction, thermal fatigue	fatigue (f4)	p1, p3, p5, p8
buckling	buckling (f5)	p9

The matrixes PF and EP were used to create EF matrix of the relationships between the potential failures (f) and functions (e) performed by the individual pairs (p). Table 2 shows the probability of failure in the range from 0 to 6. The value of 6 is the greatest probability of failure occurrence for a given function. The key failures for the investigated hydraulic cylinder are wear (f1) and seizure (f3) for pair implementing function protective (e4). These pairs are: p2, p3, p6, p7, p8, p10 which includes the sealing system. This is the key system that has an impact on the design, operation and durability of the hydraulic cylinder. It is also a most common cause of a cylinder failure. Therefore, the causes and consequences of failures of sealing systems in hydraulic cylinders need to be recognized. For this purpose, the matrix FMEA can be supplemented with the tool of quality improvement, which in this case was the cause and effect diagram.

Table 2. Function-failure matrix

		Potential failure (f)				
		1	2	3	4	5
Function (e)	1	4	4	2	1	1
	2	1	1	0	1	0
	3	2	2	2	0	0
	4	6	3	6	2	0

4. Cause and effect diagram

The diagram of cause and effect is also known as a fishbone diagram due to appearance of a fish-like graph. For the first time this method was used in Japan at Sumitomo Electric. Its purpose is a graphical representation of the relationships between effects and causes [5]. The procedure for solving the problem (effect) consists of four stages:

- determining the effect (of the problem),
- identifying possible categories of causes,
- determining the possible causes for each category,
- selecting the main cause.

For the investigated hydraulic cylinder the sealing failure was found as the main problem. Then six major reasons of causes were selected: I-repair, II-exploitation, III-cooperating components, IV-working fluid, V-design, VI-storage. For each category, possible causes affecting the sealing failure of the hydraulic cylinder were determined. In total, over twenty reasons were selected and three main ones among them. They have the biggest impact on the considered "sealing defects" problem. These are the causes of categories II, III and IV, which are:

- seizure and worn out components,
- poor quality of the working fluid,
- inadequate working conditions.

Graphical presentation of the cause and effect relationship diagram for sealing of the hydraulic cylinder is shown in Fig. 1.

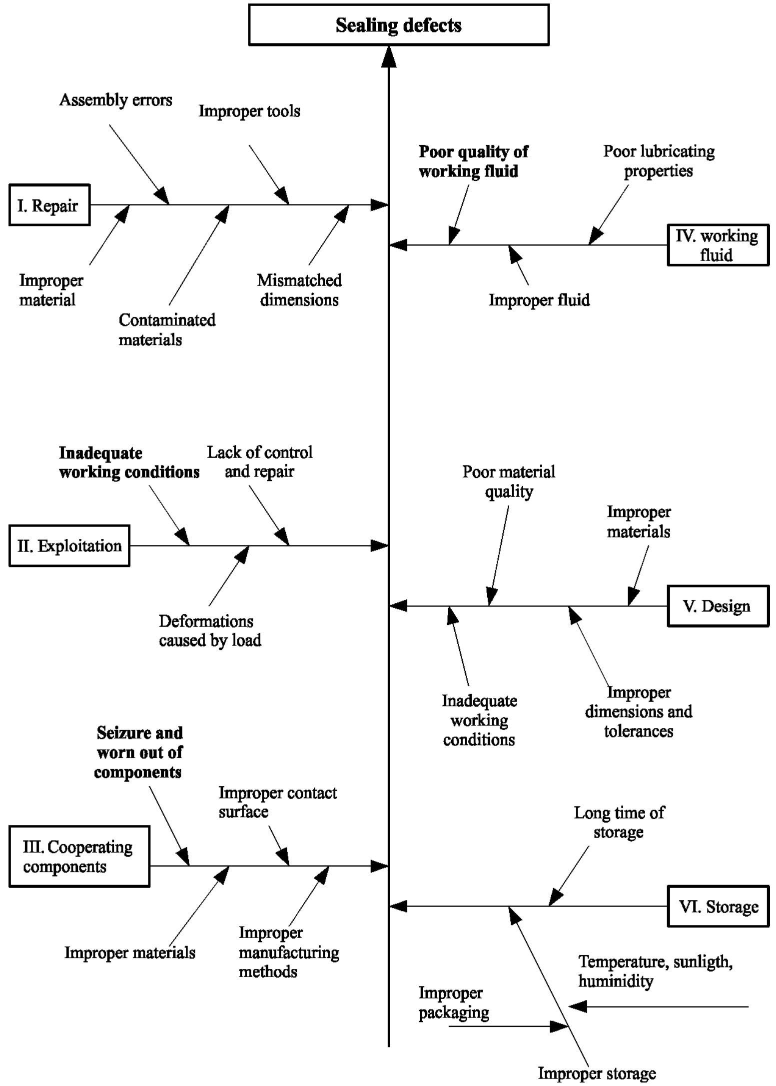

Fig. 1. Cause and effect relationship diagram for sealing system

Within the analysis of cause-effect diagram a hierarchic structure of primary cause has been created which takes into account the probability of its occurrence during cylinder operation:

- poor quality of the working fluid,
- seizure and worn out components,
- inadequate working conditions.

Table 3 shows the main reason along with the description [3, 6].

Table 3. Causes of seal damages

Failure	Description
Poor quality of the working fluid	Solid particles cause seizure of the surface of seals and guiding rings. Air bubbles cause seizure on the inner area of sealing rings on the high pressure area and breaking lip seals.
Seize and worn out components	Improper cylinder selection for operating conditions. Non axial load
inadequate working conditions:	
Extreme temperatures	Seals exposed to high temperature out of the range of working conditions becomes harder may cracks and crumbles.
Aggressive chemical agent	Some working fluids react with seals. Seals becomes sticky, stretched, dried or cracked.
High pressure	The seal may be damaged or deformed over the entire inner surface, leaks may appear.

5. Summary

The matrix FMEA analysis with the use of cause and effect diagram seems to be an effective tool for the identification of potential failures of hydraulic components. It allows to identify the main problem along with main causes which have influence on the problem appearance. As a consequence, preventive measures can be undertaken in time to eliminate the problem, and if the failure already occurred, an improvement plan prepared.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

MECHANICS

DOI: 10.4467/2353737XCT.17.180.7288

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Modelling of a pneumatic cushion in Matlab-Simulink system

Modelowanie poduszki pneumatycznej w systemie Matlab-Simulink

Abstract

The paper addresses modelling, simulation and experimental research of a pneumatic cushion. The scope of work included formulating a mathematical model based on air flow equations, building simulation model, carrying out simulations and comparing simulation results with experiments. The simulations were performed in Matlab-Simulink system, while experiments were carried out on a test bench, by means of a real industrial pneumatic cushion. The comparison of the results indicates that the created simulation model is accurate and flexible, and thus can be used in further research which concerns e.g. geometrical modifications or optimization of air consumption.

Keywords: pneumatic cushion, modelling, simulation, Matlab-Simulink

Streszczenie

Niniejszy artykuł dotyczy modelowania, symulacji oraz badań eksperymentalnych poduszki pneumatycznej. W zakres realizacji pracy weszło sformułowanie modelu matematycznego w oparciu o równania przepływu powietrza, budowa modelu symulacyjnego, przeprowadzenie symulacji oraz porównanie ich wyników z badaniami eksperymentalnymi. Badania symulacyjne wykonano w środowisku Matlab-Simulink, natomiast eksperymenty zostały przeprowadzone na stanowisku badawczym z wykorzystaniem rzeczywistej przemysłowej poduszki pneumatycznej. Porównanie uzyskanych wyników wskazuje, że zbudowany model jest dokładny i elastyczny, a zatem może być używany w przyszłych badaniach dotyczących np. zmian konstrukcyjnych lub optymalizacji zużycia powietrza.

Słowa kluczowe: poduszka pneumatyczna, modelowanie, symulacja, Matlab-Simulink

Denotations

i – chamber index, respectively: 1 – inlet, 2 – side chamber, 3 – bottom chamber,
$m_i = dm_i/dt$ – mass air flow [kg/s],
V_i, T_i, p_i – parameters of i^{th} chamber: volume [m^3], temperature [K], pressure [Pa],
R, κ – gas constant of air [J/(kg K)], heat capacity ratio [–],
M – mass of a cushion load [kg],
z_1, z_f – vertical displacement of the side chamber and width of the air gap [mm],
z – total vertical displacement of the cushion [mm],
F_a, F_g, F_s – force from air pressure in the side chamber, force of gravity, force of elasticity of side chamber walls [N],
A_2 – contact area between a bellow and a substrate [m^2],
R_1, R_2 – outer and inner radius of the contact area between a bellow and a substrate [m],
a_3, a_2, a_1, a_0 – coefficients [–],
d_1, d_2 – diameters of nozzles [m^2],
ψ – flow coefficient of nozzles [–].

1. Introduction

Pneumatic cushions are presently more and more often used in the construction of indoor transport systems inside halls or warehouses. Particularly, in industrial companies there is a continuous need to move heavy loads, such as machine tools, semi-products, components, etc. Usually, various types of lifting devices (cranes, winches, forklifts) are used for this purpose. In most cases, the devices fulfill their task properly; however, large sizes may prevent their use inside industrial buildings. On the other hand, industrial buildings are now constructed using modern technologies, providing horizontal and smooth work surfaces, including the inclination angle α not exceeding 0.1° and surface roughness Ra less than 25 μm. Fulfillment of the conditions allows for the introduction of transport systems on pneumatic cushions. The cushions are small and light devices. Particularly useful is their low height of 30–40 mm, which is stated in [1, 2]. Simple and compact design allows the operator to put the cushions under the load quickly and easily.

Earlier work of the author of this article included automation of the pneumatic cushion transport system in order to obtain the required pressure course [3] and vertical displacement [4]. This paper presents the mathematical model of a pneumatic cushion with a load, which is the base for a simulation model built in Matlab-Simulink. The simulation model was used to carry out studies on pneumatic cushion characteristics, which were then compared with the results obtained on a test bench for a real cushion.

2. Working principle of a pneumatic cushion

The primary function of a pneumatic cushion is the displacement of a load after lifting it vertically to a small height of about 15–25 mm. Vertical lifting is caused by pressure increase in the rubber bellow, while the displacement is a result of a horizontal force usually generated by the operator. Air flow between the bottom surface of the cushion and the floor forms a gap which reduces friction to a very low value (friction coefficient less than 0.001). Hence, movement of even heavy objects can be easily accomplished.

2.1. Object of study

A pneumatic cushion, whose view is shown in Fig. 1 and cross-sectional schematic diagram is presented in Fig. 2, is the object of the study. The mathematical model includes flow balances of individual volumes V_2, V_3, flow equations through nozzles Q_2, Q_3, equations defining adiabatic process and equations of motion. The resulting values are an air gap width z_f and a total lifting height of the cushion z_1.

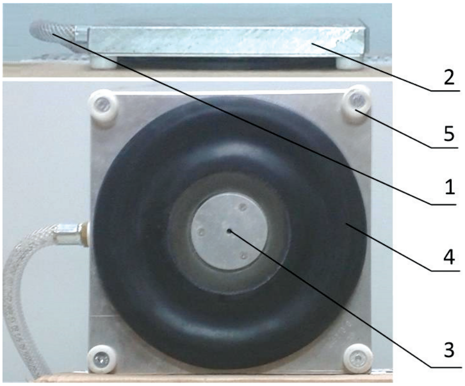

Fig. 1. The studied pneumatic cushion: 1 – inlet hose, 2 – bearing plate, 3 – outlet nozzle, 4 – rubber bellow, 5 – landing pad

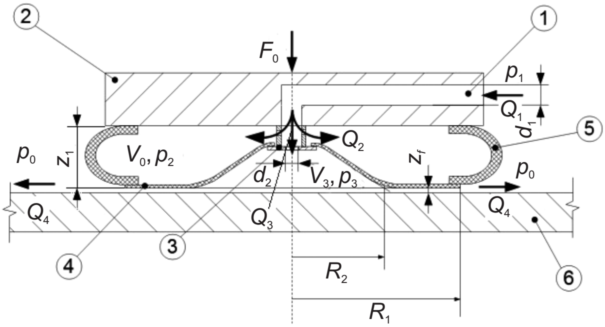

Fig. 2. Cross-sectional diagram of the cushion: 1 – inlet channel, 2 – bearing plate, 3 – outlet nozzle, 4 – bearing surface of a bellow, 5 – side surface of a bellow, 6 – substrate

2.2. Mathematical model

The mass flow rate of air at the inlet of a pneumatic cushion is determined based on the equation of continuity, assuming homogeneity of a gas stream [6]. The inlet stream $\dot{m}_1$ is divided into a side chamber stream $\dot{m}_2$ and a bottom stream $\dot{m}_3$. From the mass conservation law:

$$\dot{m}_1 = \dot{m}_2 + \dot{m}_3 \tag{1}$$

A side chamber stream $\dot{m}_2$ is modelled as filling a reservoir of a variable volume. This process can be described by a non-linear differential equation of the first order [6]:

$$V_2(t) \cdot \frac{dp_2(t)}{dt} + \kappa \cdot p_2(t) \cdot \frac{dV_2(t)}{dt} = \kappa \cdot R \cdot T_1 \cdot \frac{dm_2(t)}{dt} \tag{2}$$

Transformation of equation (2) leads to the formula which allows for the determination of the side chamber volume as a function of time:

$$\frac{dV_2(t)}{dt} = \frac{R \cdot T_1}{p_2(t)} \cdot \frac{dm_2(t)}{dt} - \frac{V_2(t)}{\kappa \cdot p_2(t)} \cdot \frac{dp_2(t)}{dt} \tag{3}$$

Equation of vertical lift of the pneumatic cushion caused by filling the side chamber can be determined from the following force balance:

$$M \frac{d^2 z_1(t)}{dt^2} = F_a - F_g - F_s - F_{pt} \tag{4}$$

where the individual forces are calculated using the following equations (5)–(8). Force from the air pressure can be calculated as:

$$F_a(t) = p_2(t) \cdot A_2(t) \tag{5}$$

while force of gravity:

$$F_g = M \cdot g \tag{6}$$

The force of elastic bellow material is estimated using a polynomial approximation on the basis of the laboratory test results:

$$F_s(z_1) = a_3 \cdot z_1^{\,3} + a_2 \cdot z_1^{\,2} + a_1 \cdot z_1 + a_0 \tag{7}$$

and the force resulting from the thermodynamic process, assuming the adiabatic change (negligible heat exchange between the air inside and outside of the chamber) is described by the following equation [6]:

$$F_{pt}(t) = K \cdot \left[V_2(0) + A_2 \cdot z_1(t)\right]^{-\kappa} \tag{8}$$

where K is a coefficient calculated on the basis of the initial conditions:

$$K = A_2 \cdot p_2(0) \cdot \left[V_2(0)\right]^{\kappa} \tag{9}$$

Air stream flowing into the bottom chamber $\dot{m}_3(t)$ through a nozzle of a diameter d_2 is determined with regard to the critical velocity. Air velocity depends on the pressure ratio $\beta = p_3/p_1$. In the case of the adiabatic change, the coefficient is constant: $\beta = 0.53$ [7]. If $p_3/p_1 \leq \beta$, the supercritical flow with the sonic velocity occurs, otherwise the velocity is lower. Thus, the theoretical mass inflow to the bottom chamber is as follows:

$$\frac{dm_3(t)}{dt} = \frac{\pi \cdot d_2^2}{4} \cdot p_1(t) \cdot \sqrt{\frac{2}{R \cdot T_1}} \cdot \Psi(t) \tag{10}$$

where $\psi(t)$ depends on pressure values:

$$\psi(t) = \sqrt{\frac{\kappa}{\kappa - 1}\left[\left(\frac{p_3(t)}{p_1(t)}\right)^{2/\kappa} - \left(\frac{p_3(t)}{p_1(t)}\right)^{(\kappa+1)/\kappa}\right]} \tag{11}$$

In the case of the supercritical flow ψ is constant: $\psi_{kr} = 0.684$, hence the equation (10) can be simplified to:

$$\frac{dm_3(t)}{dt} = 0.7594 \cdot \frac{d_2^2 \cdot p_1(t)}{\sqrt{R \cdot T_1}}. \tag{12}$$

Pressure in the bottom chamber $p_3(t)$ may be calculated from the flow balance [3]. When p_3 raises enough to compensate the load force, an air gap appears between the bottom surface of the bellow and the substrate. Vertical movement which creates the z_f gap results from the balance between the lifting force F_0 and the force of gravity F_g:

$$M \frac{d^2 z_f(t)}{dt^2} = F_0 - F_g \tag{13}$$

F_0 depends on pressure and contact area between the cushion and the substrate [5]:

$$F_0(t) = \frac{\pi \cdot p_3(t) \cdot \left(R_1^2 - R_2^2\right)}{2 \cdot \ln(R_1 / R_2)}. \tag{14}$$

Sum of z_1 (4) and z_f (13) is the total vertical displacement: $z(t) = z_1(t) + z_f(t)$.

2.3. Simulation model

The simulation model of a pneumatic cushion created in Matlab-Simulink by implementing system of equations (1) to (14) is shown in Fig. 3.

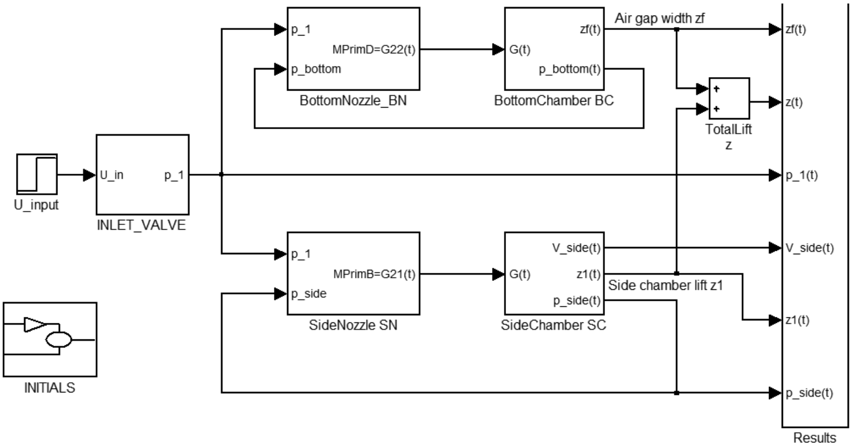

Fig. 3. Simulation model in the form of a Matlab-Simulink block diagram

The main components of the model represent proportional relief valve INLET_VALVE, two nozzles leading to the SN side chamber and the BN bottom chamber, and the same SC and BC chambers. Input signal in the form of a step function is generated by the U_input block. Other blocks are used to set the initial values and acquire the simulation results.

3. Plan and results of experiments

The simulations included the determination of the $z_f(t)$ width gap and $z(t)$ total vertical displacement depending on the load and the inlet pressure. The following values of the load were tested: from $M_1 = 50$ kg to $M_5 = 250$ kg every $\Delta M = 50$ kg. Similarly, the inlet pressure was from $p_{1\_1} = 0.15$ MPa to $p_{1\_5} = 0.20$ MPa every $\Delta p_1 = 0.01$ MPa. Example results of $z(t)$ and $z_f(t)$ obtained for $p_{1\_5} = 0.20$ MPa and selected load values are presented in Fig. 4a and Fig. 4b, respectively.

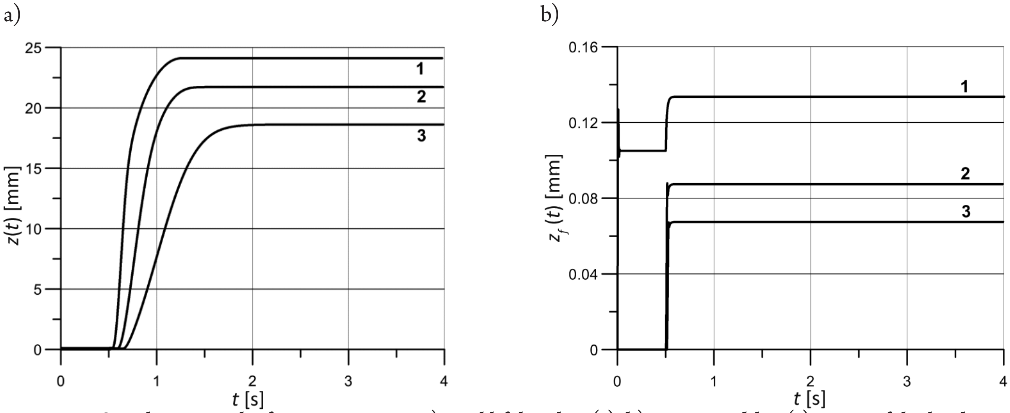

Fig. 4. Simulation results for $p_1 = 0.2$ MPa: a) total lift height $z(t)$, b) air gap width $z_f(t)$. Mass of the load: 1 – $M = 50$ kg, 2 – $M = 150$ kg, 3 – $M = 250$ kg

Figure 5 shows a collective summary of the simulation results in the form of a 3D surface. The simulation results indicate that in response to the step function of the input pressure, in each case an asymptotic equilibrium position has been obtained. No pulses at the startup or in the steady state were observed. Total vertical displacement of the z cushion varied from 13.1 mm to 22.2 mm for p_1 = 0.15 MPa and from 18.6 mm to 24.1 mm for p_1 = 0.20 MPa, depending on the load. The air gap width in these cases varied respectively from 60.9 μm to 129.0 μm and from 67.5 μm to 133.6 μm.

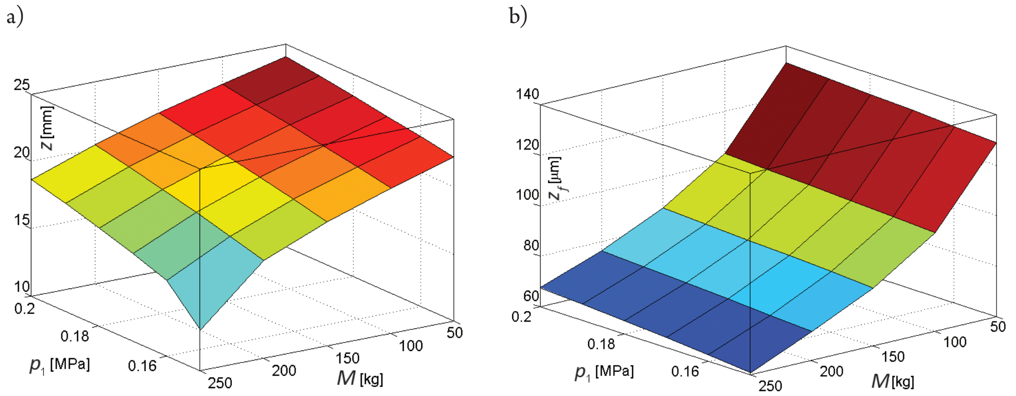

Fig. 5. Total lift height z and air gap width z_f against inlet pressure p_1 and load M

The simulation results were compared with the results of stand tests conducted using a real pneumatic cushion. Exemplary comparison of the results obtained for the inlet pressure p_1 = 0.20 MPa and the load $M = M_1$ = 50 kg and $M = M_5$ = 250 kg are shown in Fig. 6. The comparison showed high compliance level, since the maximum relative error in the steady state is less than 5% for the M = 250 kg, and approximately 1% for M = 50 kg.

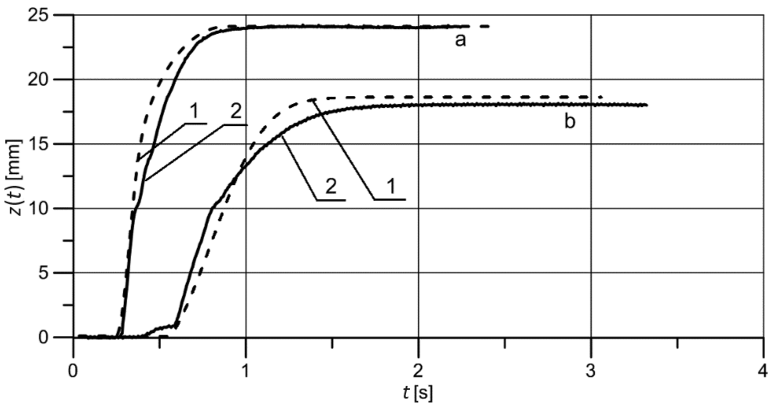

Fig. 6. Comparison of simulation (1) and laboratory (2) results for p_1 = 0.2MPa; mass of the load: a) M = 50 kg, b) M = 250 kg

4. Summary

This work applies to modelling and examining of operational characteristics of a pneumatic cushion. First, a mathematical model was built in the form of set of differential equations. Then the model has been implemented in Matlab-Simulink. Simulation studies were carried out for different values of the inlet pressure and the load. The results of simulation studies were compared with those obtained from the laboratory experiments. A satisfactory compliance has been obtained, which proves correctness of the model and research assumptions. The created model will be used in further research in order to improve stability and reduce air consumptions of pneumatic cushions.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

MECHANICS

DOI: 10.4467/2353737XCT.17.181.7289

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The effect of selected natural fillers on the mechanical properties of low-density polyethylene

Wpływ wybranych napełniaczy naturalnych na właściwości mechaniczne polietylenu małej gęstości

Abstract

The popularity of using natural waste products in different branches of industry, including polymer processing, results from the emphasis of international nature conservation organizations on ecological and environmental problems, such as recycling, storage and the disposal of waste products. This paper investigates the effect of two natural fillers: wheat bran and pumpkin seeds obtained from food industry waste products, on selected mechanical properties of LDPE molded pieces. The polymer blends are examined with respect to their basic mechanical properties and microstructure.

Keywords: natural waste material, mechanical properties, wheat bran, pumpkin seeds

Streszczenie

Popularyzacja wykorzystania odpadów naturalnych w różnych gałęziach przemysłu, m.in. w przetwórstwie tworzyw, związana jest z naciskiem światowych organizacji odpowiadających za ochronę środowiska na kwestie ekologiczne, takie jak recykling oraz składowanie i utylizacja odpadów. W artykule przedstawiono badania wpływu dwóch napełniaczy, otrębów pszennych oraz łusek pestek dyni, stanowiących odpady produkcyjne przemysłu spożywczego, na wybrane właściwości mechaniczne wyprasek wtryskowych z PE-LD. Przeprowadzono badania podstawowych właściwości wytrzymałościowych oraz dokonano analizy struktury mikroskopowej otrzymanych kompozycji polimerowych.

Słowa kluczowe: odpady naturalne, właściwości mechaniczne, otręby pszenne, pestki dyni

1. Introduction

In the recent years, polymer blends containing natural fillers have been more and more widely used in the processing industry, particularly in polymer processing. Polymer blends have unique properties, which is why they are used in different branches of industry. In order to obtain products with the required functional properties, polymers are physically modified by the use of fillers. The properties of the thereby produced composite material are significantly affected by interactions between the polymer matrix and the filler. In some cases, particularly when their concentration is low, powdered fillers can act as heterogeneous nucleates in the polymer crystalline phase [1–4].

The physical modification of polymers is usually done using solid substances with a relevant degree of refinement. These substances predominantly include dyes, pigments, organic and non-organic fillers, reinforcing agents – usually fibrous and powdered substances, glass balls or their blends, the so-called hybrid fillers [5]. Modifiers can enhance some physical and chemical properties, but at the same time, other properties may decrease. This results from the differences in the interaction between polymer particles and the substance being modified. In the recent years, polymers have been more and more often modified using either micro-, submicron- and nano-refined materials, or materials, which naturally occur in such forms [6]. Previous experimental results demonstrate that it is a very promising, fast developing field of knowledge, which opens up new possibilities, impossible to explore using traditional modification methods [5].

There are numerous methods of classifying physical modification by fillers [7]. It seems, however, that the most effective way to classify filler-induced physical modification of plastics is according to the filler function and particle size. The polymer matrix keeps the blend together due to the adhesion of elementary particles of the filler to the polymer. Smaller particles bond more easily and form a more durable structure [8, 9].

The aim of the study was to determine the effect of powdered fillers obtained from renewable resources, such as wheat bran and pumpkin seed hulls, on the mechanical properties of low-density polyethylene (LDPE) filled with these natural fillers. In particular, the study examined the relationships between the basic strength properties of the produced injection molded pieces and filler contents. In addition, it attempted to explain the observed phenomena via an analysis of the matrix-filler system.

2. Experimental

2.1. Test stand

The tests were performed using the ARBURG ALLROUNDER 320C single-screw injection molding machine (Loßburg, Germany), provided with a two-cavity mold for manufacturing standard specimens in compliance with ISO 527-1:2012.

The static tensile tests were performed on the produced composite molded pieces using a standard testing machine, Z010 AllroundLine from Zwick Roell (Ulm, Germany). The

Z010 testing machine has a maximum tensile force of up to 10 kN and a tensile rate up to 2000 mm/min.

Hardness measurements were conducted by the Shore method using the ART.13 hardness tester manufactured by Affri System Hardness Testers (Induno Olona, Italy). This hardness tester has a unique digital system for data processing from the gauge head. It is also provided with an LCD reader for all Shore and automatic detection of the probe and hardness scale.

The examination of the morphology of the specimen cross sections was performed using the Nikon Eclipse LV100ND microscope (Warsaw, Poland), equipped with the DS-U3 camera and NIS-Elements AR 4.20.00 software.

2.2. Materials

The study was conducted using powdered low-density polyethylene, DOWLEX® (LDPE) 2631.10EU, manufactured by The Dow Chemical Company (Schkopau, Germany). This plastic is used for producing a plastic film by blow molding, casting, extrusion molding with a coating, rotational casting and injection molding. DOWLEX® is used in many branches of the industry, including the manufacture of industrial, food and medical packaging. Some of its modifications are also used for manufacturing sanitary products, consumer products as well as dairy products. Table 1 lists the properties of the tested polymer after the specifications provided by the manufacturer.

Table 1. Basic properties of the polymer used in the tests

Property	Value
Density 23°C, [kg/m^3]	935
Melt mass flow rate (230°C; 2.16 kg), [g/10 min]	7
Tensile stress at yield, [MPa]	17.8
Tensile strain at yield, [%]	419
Shore hardness, [°Sh D]	56
HDT temperature, B (0.45 MPa) [°C]	52
Vicat softening temperature (A120 (120°C/h 10N), [°C]	115
Melting temperature, [°C]	124

One of the fillers used in the tests was wheat bran (WB), which is the outer layers of the wheat grain. Bran is a byproduct of the milling process in which wheat grain is conversed to clean, white flour. It has the shape of thin flakes, which are several millimeters in size. The main ingredient of wheat bran is raw fiber comprising a sum of fibrous substances, such as cellulose, lignin and hemicellulose; apart from that, wheat bran contains phytic acid, oligosaccharides and non-starch polysaccharides as well as small amounts of fats and proteins [10]. The hardness of WB is approx. 0.35 g/cm^3 [10].

The other natural fillers used in the tests were pumpkin seed hulls obtained from a company dealing with the purification and sales of pumpkin seeds (Fig. 2a). Hulls (Fig. 2b) are a waste material produced by the mechanical hulling and purification of pumpkin seeds. The main component of pumpkin seed hulls are mixtures of polysaccharide substances (cellulose, hemicellulose, pectin, gum, slime mold) and non-polysaccharide substances (lignin) [11].

a) b)

Fig. 1. General view of: a) coarse bran, b) finely ground bran

a) b)

Fig. 2. General view of: a) pumpkins and their seeds and b) pumpkin seed hulls

2.3. Tested parameters

Given the objective of the study, a set of key parameters was established to describe the investigated processes, including the preparation of injection molded pieces, tensile tests as well as hardness measurements. These parameters were divided into the following groups:

Direct factors:

- maximum tensile force, F_Z *N*,
- yield point, F_R *N*,
- change in the measuring length at yield Δl_R, mm,
- change in the measuring length at maximum tensile force Δl_Z, mm,
- specimen size, mm.

Indirect factors:

- cross-sectional area of the specimen, *A*, mm^2.

Resulting factors:

- Young's modulus *E*, MPa,

- maximum tensile stress σ_z, MPa,
- tensile stress at yield σ_r, MPa,
- tensile strain ε_z, %,
- tensile strain at yield, ε_r, %,
- hardness H, °ShD.

Variables:
- filler content in the specimen: 5, 10 and 15 wt%.

Constant factors:
- filler grain diameter: 0.4–0.6 mm,
- temperature of the plasticizing unit of the injection molding machine in particular zones, t_{I} – 130°C, t_{II} – 135°C, t_{III} – 140°C, t_{IV} – 150°C,
- temperature of the injection mold, t_f = 30°C,
- injection pressure, p = 100 MPa,
- polymer injection time, T_w = 2 s,
- polymer plasticization time in the plasticizing unit, T_u = 4 s,
- polymer cooling time in closed mold cavity, T_c = 20 s,
- specimen tension time, v = 100 mm/min.

Disturbing factors:
- electric voltage: 219–241 V,
- relative air humidity: 55–65%,
- ambient temperature: 20–24°C.

The results demonstrate that the disturbing parameters have a negligible effect on the measurements, and can thus be omitted in the results discussion.

3. Methods

Wheat bran was first ground using a grinding mill. After that, fractions with different grain sizes were separated using sieves with mesh sizes of 0.4 mm and 0.6 mm. This led to the production of one fraction with its grain size ranging between 0.4 mm and 0.6 mm. The pumpkin seed hull filler was prepared in a similar way.

Prior to starting the injection molding machine, a blend of the low-density polyethylene and the filler was prepared. 500 g of the polymer was mixed with the tested filler content with the addition of adhesion-promoting carbofunctional silane marketed under the name of aminopropyltriethoxysilane [12]. The materials were mixed, and the produced polymer blend was fed into the hopper of the injection molding machine. The molded pieces produced during the first 10 cycles of the injection molding process were rejected. Only successively produced molded pieces were used as test specimens. The injection molding process was continued until the plasticizing unit of the machine was completely empty. After that, the hopper was loaded with another dose of the prepared mixture, this time with another tested filler content and grain size.

The use of wheat bran and pumpkin seed hulls (and many other natural materials) as polymer fillers means that the processing must be conducted at relatively low temperatures due to the thermal decomposition of organic substances and the intensive liberation of gases.

Static tensile tests were performed using the testing machine on 10 injection molded pieces in compliance with the ISO 527-1:1998 standard [13].

Hardness measurements were conducted in accordance with the procedure described in the ISO 527-1:2012 standard [14]. Twenty measurements were made on 10 different molded pieces.

4. Results and discussion

4.1. Strength tests

The static tensile test results are given in the form of diagrams in Figures 3 through 8. The diagrams illustrate the relationships between the mean values of Young's modulus E, tensile strength, tensile stress at yield, tensile strain at the tensile strength and tensile strain at yield versus the filler contents in the tested injection molded pieces.

The relationships between Young's modulus and the filler type and content are illustrated in Fig. 3. The values of Young's modulus of the test specimens increase with increasing filler content, irrespective of the filler type. The maximum values of this parameter are 452 MPa (wheat bran) and 427 MPa (pumpkin seed hulls), which is equal to an increase by 23.49% and 16.66%, respectively, compared to the initial value. Both types of filler, wheat bran and pumpkin seed hulls, significantly increase the rigidity of the tested injection molded pieces, which results from constraining the movement of polymer chains due to the presence of the filler. Similar observations about the relationship between Young's modulus and natural filler content were made in studies in which the following were used as fillers: rape straw [15], leaves [16], nutshells [17], oat hulls [18], wood powder [19] and switchgrass [20].

The relationships between the tensile strength and the filler type and content are shown in Fig. 4. The tensile strength of polyethylene filled with wheat bran and pumpkin seed hulls is lower than that of unfilled polyethylene in the entire tested range of filler content. Irrespective of the applied filler type, the addition of the lowest tested filler content (5 wt%) leads to a decrease in the tensile strength. The lowest tensile strength of the specimens is observed at 15 wt% filler content. The tensile strength of the specimens is the same for both filler types –1.35 MPa, which is equal to a 10.11% decrease in its initial value. The mechanical properties of composite materials depend on the filler's ability to integrate into the polymer microstructure. A survey of the literature on the subject reveals that the properties of composite materials can be enhanced by, among others, the optimization of amount, size, distribution and shape of the filler grain. A similar pattern of variations in the tensile strength of injection molded pieces was observed in other research studies on fillers obtained from renewable sources of energy, such as peanut shells [17], wood flour [21] and carbon filler Shungite III [22].

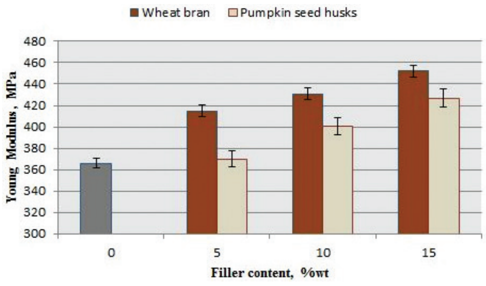

Fig. 3. Young's modulus versus filler content

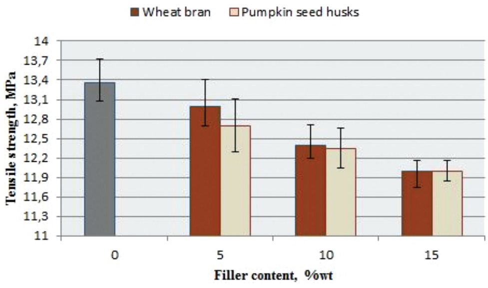

Fig. 4. Tensile strength versus filler content

Figure 5 illustrates the relationship between the tensile stress at yield versus the filler content. In the entire tested range of filler contents, those of wheat bran and pumpkin seed hulls alike, this parameter first decreases and then starts to increase. The addition of a small amount (10 wt%) of the filler leads to a decrease in the tensile stress of the specimens by 9.5 MPa (wheat bran) and by 7.9 MPa (pumpkin seed hulls), which corresponds to, respectively, 57.92% and 51.82% decrease in the initial value. The lowest tensile stress can be observed when adding a 10 wt% content of the wheat bran-based filler. The decrease in the tensile stress may be caused by the loss of the adhesion of small filler particles to the polymer matrix. Adhesion on the polymer-matrix interphase is a crucial factor and often has a decisive effect on the properties of composite materials [23]. Polymer adhesion depends on its adsorption on the filler surface, the wettability of filler grains by filler melt, and the bonding formed between the filler and the polymer.

The relationship between the tensile stress at break and the filler type and content is illustrated in Fig. 6. The diagram clearly demonstrates that the strains decrease with an increase in the filler content, regardless of its type. The decrease in strains versus the filler content is more rapid for polyethylene filled with pumpkin seed hulls. The addition of 15 wt% of this filler leads to a decrease in the strains by 27.7%, when compared to the strains obtained for the specimens of unfilled polyethylene, i.e. 13 MPa. The variations in this parameter for the specimens of polyethylene filled with wheat bran are not that considerable. On adding the highest tested filler content, the strain decreases by 15.4%, so the decrease is almost two times lower than that that observed for the specimens filled with pumpkin seed hulls. The decrease in the strains due to the applied stress with increasing the filler content indicates an increase in rigidity of the material. This trend corresponds with the observed variations in Young's modulus (Fig. 3). This parameter describes eleastic properties of a material, so its increase points to an increase in material's rigidity [24, 25].

Figure 7 illustrates the relationship between the tensile strain at yield and the filler types and contents. The diagram shows a decreasing tendency of the tensile strain at yield. The addition of even the smallest filler content results in a rapid decrease in the tensile strain at yield. The addition of 5 wt% wheat bran-based filler to the polymer matrix leads to a decrease in the maximum tensile strains from 435% (unfilled polyethylene) to 190%. On increasing this filler's content to 10 wt%, the maximum tensile strain is reduced to 36%; when the filler content is increased to 15 wt%, the tensile strain at yield is decreased by almost 20 times, reaching the value of 24%. The pattern of variations in the tensile strain of polyethylene filled with pumpkin seed hulls is similar, and the changes occur even more rapidly. At 5 wt% pumpkin seed filler, the tensile strain at yield is 98%, which is two times lower than in the case of the bran-based filler; on the addition of 15 wt% filler, the tensile strain at yield is 17.5%.

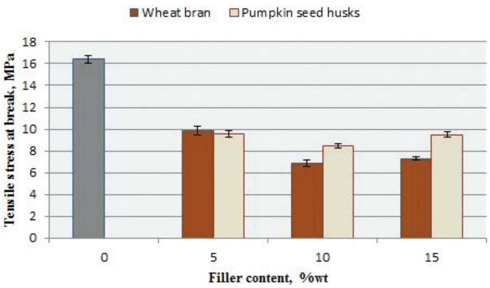

Fig. 5. Tensile stress at break versus filler content

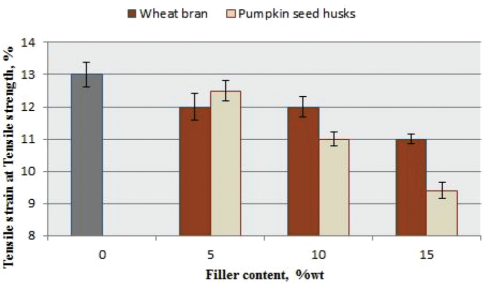

Fig. 6. Tensile strain at tensile strength versus filler content

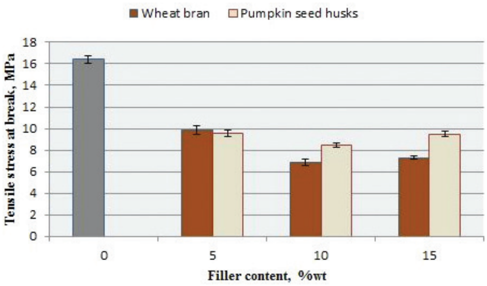

Fig. 7. Tensile strain at yield versus filler content

The decrease in the elasticity of polymer compositions described by tensile strain at yield probably results from the filler grain size. During tension, there occurs cavitation, i.e. the formation of empty spaces at the surface of filler grains undergoing tension. If the grain size is considerable, the above cavities may promote crack initiation leading to the premature formation of a fracture [26, 27]. Moreover, ground pumpkin seed hulls have sharp edges which may damage polymer chains during tensile testing, thus reducing the maximum tensile strain of the polymer composition to an even higher degree.

4.2. Hardness of the injection molded pieces

The relationship between Shore hardness D and the filler type and content is illustrated in Fig. 8. The tested fillers exert a different effect on the polymer's properties. The application of 5 wt % wheat bran filler results in a decrease in the hardness of the entire polymer blend by approx. 3.4%. With a further increase in the wheat bran content, the polymer's hardness is gradually increasing until it reaches 51.24°ShD; this value is, however, lower than the hardness of the unfilled low-density polyethylene (51.68°ShD) by approx. 0.9%. It can, therefore, be claimed that in the tested range of filler content, the wheat bran filler does not have a significant effect on the hardness of the tested polymer blend. In turn, the addition of the pumpkin seed-based filler to the polymer leads to a clear increase in the plastic's hardness. The addition of the smallest tested filler content, i.e. 5 wt%, makes the hardness increase by approx. 3.9%. With a further increase in the pumpkin seed filler content, the hardness of the polymer blend increases until it reaches 54.73°ShD for 15 wt.% filler, which amounts to an increase by 5.9% compared to the initial value. It must be underlined that the measured hardness of unfilled polymer is lower than the data provided by the manufacturer, which is probably due to the course of the processing process.

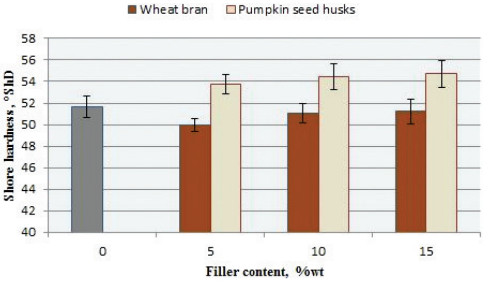

Fig. 8. Shore hardness versus filler content

The hardness of a polymer blend depends on factors such as filler hardness, filler grain size and the interactions on the filler-polymer matrix interphase. Powdered filler grains can act as nucleates in the polymer crystalline phase, which results in an increase in hardness of material [15–17]. Moreover, this can also be due to the fact that, unlike wheat bran, pumpkin seed hulls have a considerable hardness.

4.3. Morphology of produced polymer blends

The experiments involved performing microscopic examination of the cross section of the produced polymer blends containing 5, 10 and 15 wt.%, respectively. The images of the cross-sectional morphology of the produced injection molded pieces are given in Fig. 9.

The examination of the morphology reveals non-uniform distributions of both types of natural fillers. One can observe the presence of varying size particles and agglomerates. The micrometric filler particles, which probably have a higher free surface energy than low-density polyethylene, show a tendency for forming agglomerates in such a center (Fig. 9b, c, e, f). This is undesired because it leads to a decrease in the contact surface between filler and polymer, which, in turn, results in reduced adhesion.

Examining the images one can conclude that the refined filler grains do not have uniform shape or size. This probably results from the initial grain shape of the fillers and their mechanical properties as well as the nature of the grinding process. The grains produced by mechanical grinding have the shape of plates, with one of their dimensions exceeding the tested range. Given its marginal hardness and rigidity, wheat bran tends to roll up. The non-symmetric shape of filler grain and the considerable differences between grain length and width may lead to the asymmetry of properties.

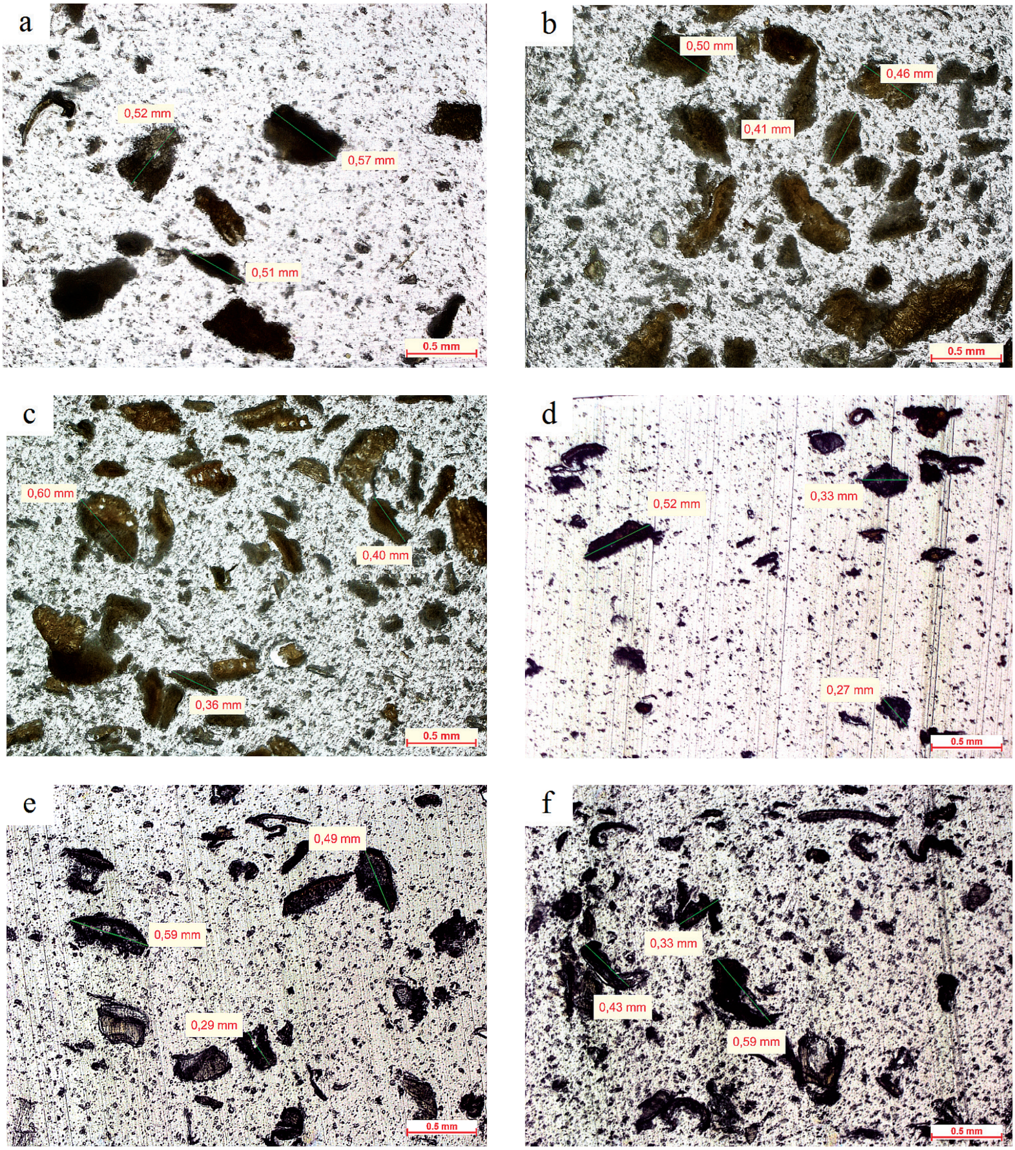

Fig. 9. Images of the cross sections of the tested polymer compounds filled with pumpkin seed hulls (a–c) and wheat bran (d–f) at 5/10/15 wt.%, respectively

5. Conclusion

The exhaustion of petrochemical raw materials and the necessity of CO_2 emission reduction led to imposing stringent regulations on environment protection. In effect, the problem of blending polymer matrix materials and fillers based on renewable resources has become one of key research areas. The modification of polymers by means of natural fillers causes many changes in terms of both polymer processing itself and the mechanical properties of products and the morphology of their structure. The examination of changes in the properties of thereby modified plastics is significant in terms of their applications.

Natural fillers are widely available and usually come as waste material in different industrial branches, for instance, the food, clothing or woodworking industry. The use of such waste materials is significant in terms of recycling. It must, however, be remembered that the use of natural materials may cause some inconvenience during the processing. The polymer matrix should be suitable for processing at temperatures, which are lower than those of thermal decomposition of organic compounds.

Wheat bran and pumpkin seed hulls can be successfully used as polymer fillers in the injection molding process. The use of these fillers leads to an increase in the hardness of specimens, which is proved by the increase in Young's modulus. However, one can observe a decrease in the tensile strength and the corresponding strain; the maximum tensile strain at yield decreases rapidly, too. The above results and the results reported in the literature demonstrate that this phenomenon is typical of natural fillers. The variations in hardness depend to a greater extent on the filler type and its properties – the filler either increases the specimen hardness (pumpkin seed hulls) or has no significant effect thereon (wheat bran).

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017
MECHANICS
DOI: 10.4467/2353737XCT.17.182.7290

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Simulation studies on ring upsetting using the abaqus software

Badania symulacyjne spęczania pierścieni w programie abaqus

Abstract

In this paper, a simulation and an experimental analysis of upsetting a cold ring placed between two rigid plates were conducted. When designing a new process, it is preferable to carry out the simulation studies using FEM, which allow for the prediction of the course and proper selection of process conditions. Due to the complexity of phenomena that occur during plastic formation, it is essential to have a good description of contact phenomena and properties of material in the plastic state. The computer simulation was performed for a specific material – a thick plate of hot-rolled carbon steel with fixed initial dimensions of rings and different values of the coefficient of friction.

Keywords: upsetting, friction, FEM simulation

Streszczenie

W niniejszym artykule przeprowadzono analizę MES spęczania na zimno pierścienia umieszczonego pomiędzy dwoma sztywnymi płytami. Symulację komputerową przeprowadzono dla konkretnego materiału – blachy grubej walcowanej na gorąco ze stali niskowęglowej przy ustalonych wymiarach początkowych pierścieni i różnych wartościach współczynników tarcia. Krzywą wzmocnienia wyznaczono w badaniach własnych. Obliczone wymiary pierścieni oraz wartości sił spęczania porównano z wynikami doświadczalnymi. Wyraźnie widać silny wpływ warunków tarcia na niejednorodność odkształceń, a zwłaszcza na charakter zmian średnic wewnętrznych. Wykonano badania doświadczalne spęczania z użyciem gładkich i chropowatych kowadeł na sucho i ze smarem, zmieniając w ten sposób warunki tarcia na powierzchniach kontaktowych.

Słowa kluczowe: spęczanie, tarcie, analiza MES

1. Introduction

While designing a new process, it is preferable to carry out simulation studies. They allow for the prediction of the process and help to check the proper selection of process conditions. There are many commercial programs which allow us to carry out this type of study. Essa et al. [4] used Ansys, which is general finite element method software, for the examination of the behavior of bi-metallic components during the cold upsetting process. Luo et al. [12] simulated sheet metal flanging and upsetting process by means of the MSC.Marc software. There is more special software such as e.g. eta/DYNAFORM used for modelling of the stamping process by Hojny et al. [7]. Due to the complexity of phenomena that occur during plastic formation, it is essential to have a good description of the contact phenomena and properties of material in the plastic state.

The problem regarding computer modeling of metal forming processes has been a subject of many scientific works. The article by Behrens and Schafstall [1] is dedicated to 2D and 3D modeling of forging processes considering friction forces. Another author, Lacki [11] discusses the use of various models of friction in computer simulations. The other work by the same author Lacki [10] concerns the modeling process of upsetting. Khoei et al. [8] present a calculation algorithm for modeling friction in processes of compressible material forming.

Coulomb friction law can be successfully used in the analysis of a metal forming process provided that the assumed values of the friction coefficient correspond to the actual conditions. Gieżyńska [5] draws attention to the diversity of phenomena occurring at the contact surfaces under high unit pressures and presents a number of experimental methods which allow for setting coefficients of friction in metal forming processes. In the methods, also discussed by Morawiecki et al. [14], independent measurements of the tangential force (T) and the normal force (N) to the contact surface are utilized, or the $T/N = \mu$ ratio is directly determined (i.e. in the rolling process, where $\mu = \tan(a)$ is a limit value of a gripping angle). Methods of experimental research of friction in elastic and plastic areas of the contact surface are described by Tajdari and Javadi [17].

The occurrence of stresses of different values on contact surfaces, caused by friction, significantly affects the shape of the deformed object. Therefore, coefficients of friction can also be set by studying changes in the dimensions of samples deformed under various conditions. The essence of the method involves the use of the boundary problem solution in the equations of the theory of plasticity which describe the change of sample's dimensions with fixed initial dimensions for assumed values of the friction coefficient. The theoretical relationship between the strain and friction conditions can be represented in the following general form:

$$F_i(e_1, e_2) = 0 \text{ for } \mu = \text{const} \tag{1}$$

where independent variables e_1 and e_2 characterize the deformation state. Deformations or the final dimensions of samples can be taken as the e_1 and e_2 variables (from the fixed initial dimensions).

Male and Cockroft [13] inspired by Kunogi's idea [9] provided a suitable theoretical solution and developed a nomogram showing functions (1) for upsetting rings of fixed dimensional proportions $D_0 : d_0 : h_0 = 2{:}1{:}0.7$ (Fig. 1), by assuming that:

$$e_1 = \varepsilon_h = \frac{h_0 - h_1}{h_1}, \tag{2}$$

$$e_2 = \frac{d_0}{d_1}, \tag{3}$$

The friction coefficient is determined by measuring the inner diameter *d* and height of the ring after upsetting; see Burgdorf [2]. The nomogram developed by A.T. Male, and M.G. Cockford is cited by many authors, including Gieżyńska [5], Sofuoglu and Gedikli [16]. Further studies of this method were conducted among others by Wang and Lenard [18] and also Pawelski et al. [15]. It should be noted that, using current advancement of computational methods (FEM), nomograms for determining friction coefficients can be built on the basis of deformation of samples which are not ring-shaped.

A new method (ODBET) developed by Sofuoglu and Gedikli [16] is worth mentioning. It consists of pressing cylindrical samples on the lower anvil, while the top anvil has an edge-rounded hole. Therefore, a counter extrusion of material into the hole of the upper anvil occurs. The height of portion of the sample squeezed into the hole, as well as other dimensions depend on the coefficient of friction at the contact surfaces. The authors developed appropriate nomograms using ANSYS software. It should be mentioned that earlier a similar method had been proposed by Herold [6], wherein the friction coefficient was determined based on the height of the rectangular portion of the sample formed by extrusion into the slot of the upper anvil.

As it turned out, the main advantage of the method of upsetting rings (in addition to the simplicity of its implementation) is strong influence of friction on the e_1 and e_2 variables, making it possible to detect even small changes of the friction coefficient. The nomogram developed by Male and Cockroft [13] is universal, independent of the type of material and thermodynamic conditions of deformation process. Because the characteristics of the material and thermodynamic conditions have a significant influence on the deformation, in this article it is proposed that the F_i functions are determined individually for different materials, initial ratios of ring dimensions and strain conditions.

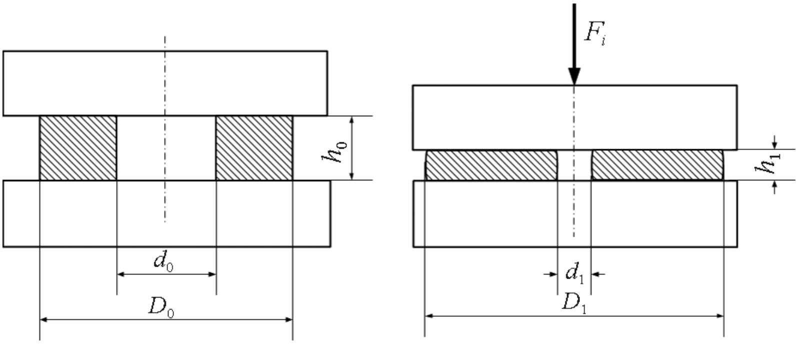

Fig. 1. Scheme of the ring before and after upsetting (on the right)

2. Material model and conditions of deformation

Rings made of the S235JR steel with dimensions: D_0 = 20 mm, d_0 = 10 mm and h_0 = 8 mm were used in the simulations. It was assumed that the materials were homogeneous, isotropic, elastic-plastic, with the isotropic hardening and incompressible in terms of plastic. Cold deformation is carried out under isothermal and quasi-static conditions. With these assumptions, the following Huber-Misses condition is valid:

$$3J_2' - \sigma_p^2\left(\bar{\varepsilon}^{pl}\right) = 0, \tag{4}$$

as well as the constitutive equation of Prandtl-Reuss:

$$d\varepsilon_{ij} = \frac{1+\upsilon}{E}\left(d\sigma_{ij} - \frac{\upsilon}{1+\upsilon} d\sigma_{kk}\delta_{ij}\right) + \frac{3d\bar{\varepsilon}^{pl}}{2\sigma_p \bar{\varepsilon}} S_{ij}, \tag{5}$$

where:

J_2' – second invariant of the deviatoric stress tensor **S**:

$$J_2' = \frac{1}{2}\mathbf{S}:\mathbf{S}, \tag{6}$$

$$\mathbf{S} = \sigma - \frac{1}{3}\sigma:\mathbf{I}, \tag{7}$$

where:

ν – Poisson's ratio,

E – Young's modulus,

ε^{-pl} – equivalent plastic a plastic strain:

$$\bar{\varepsilon}^{pl} = \int \sqrt{\left(\frac{2}{3} d\varepsilon^{pl} : d\varepsilon^{pl}\right)}. \tag{8}$$

3. Experimental identification of parameters describing the material

Parameters describing the material were defined in the uniaxial tension and compression tests. The values of equivalent strain and yield stress in the tensile tests were determined by the following formulas:

$$\bar{\varepsilon}^{pl} = \ln\left(1+\varepsilon_{\text{nom}}\right) - \frac{\sigma_{tr}}{E}, \tag{9}$$

$$\sigma_p = \sigma_{tr} = \frac{P}{F_0}\left(1+\varepsilon_{\text{nom}}\right), \tag{10}$$

where:

$$\varepsilon_{\text{nom}} = \frac{\Delta l}{l_0}, \tag{11}$$

l_0, F_0 – respectively: length and area of measuring section,
P – force,
s_{tr} – actual stress,
e_{nom} – relative strain.

Compression tests were used for large deformations (). In these tests, conditions similar to the absence of friction were provided. Cylindrical samples with dimensions $d_0 = h_0 = 7$ mm with greased recesses in the faces and polished anvils were used. The yield stress was determined by introducing an amendment which takes into account the impact of low friction ($\mu \approx 0.5$) on the surface of the anvils, according to Morawiecki et al. [14]:

$$\sigma_{tr} = \frac{4P}{\pi d^2} = \frac{2\sigma_p h^2}{\mu^2 d^2}\left[\exp\left(\frac{\mu d}{h}\right) - \frac{\mu d}{h} - 1\right]. \tag{12}$$

The equivalent strain was calculated from the following formula:

$$\bar{\varepsilon}^{pl} = 2\ln\frac{d}{d_0}. \tag{13}$$

In order to determine the elastic constant, measurements of a low longitudinal and transverse strain of the tensile were carried out. Electro strain gauges 1XY91-3/120 glued on the measuring sections of the samples were used for this purpose. Elastic constants were as follows: Poisson's ratio $v = 0.28$, Young's modulus $E = 2.09\ 10^5$MPa.

Fig. 2 shows the hardening curve used in the calculations approximated by the function:

$$\sigma_p = 256 + 572\varepsilon^{-0.629}. \tag{14}$$

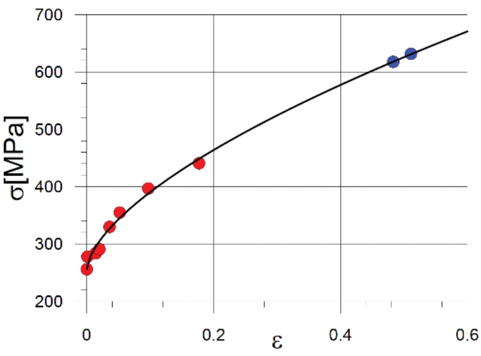

Fig. 2. The hardening curve determined for calculations (red points denote tensile measurements, blue points – compression measurements)

4. FEM analysis

A FEM analysis of the ring upset was carried out in the ABAQUS software [3]. The ring, geometrical models of fixed anvil and movable anvil were built for this purpose. The elements have been built as separate parts of the assembly. When depositing the parts to the FEM analysis, it was assumed that the fixed anvil is rigid, movable anvil is also rigid and can move only vertically. The ring model was built as a deformable axially symmetric (Fig. 3). Ring dimensions were set as follows: D_0 = 20 mm, d_0 = 10 mm, h_0 = 8 mm. The FEM model of the ring was constructed by imposing the following conditions: *max size* – 0.2 mm, *max deviation factor* – 0.1. The interaction between the walls of the ring and anvils was defined as a *type of contact*, assuming a constant coefficient of friction μ. In the normal direction, the pressure overclosure parameter was assumed as *Hard Contact*, *constraint enforcement* as *penalty* and *contact stiffness* as *linear*.

Fig. 4 shows the results of the ring deformation obtained for displacement of the anvil equal to 3 mm and Fig. 5 – for a 5 mm displacement, with the friction coefficient $\mu = 0.07$. As can be seen from the comparison of the drawings, the level of deformation significantly affects the cross-sectional shape of the ring. A similar phenomenon can also be observed for the results obtained for the coefficient of friction of 0.12 and 0.577 (Figs. 6–9). The simulation results confirm that the friction coefficient value has a particular influence on the inner diameter of the ring. At low values of the friction coefficient, inner diameters of the ring are subject to a small change. However, if the value of friction coefficient is above 0.5, the value of an inner diameter decreases rapidly.

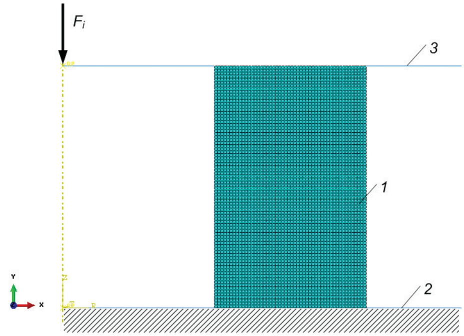

Fig. 3. Model mesh: 1 – deformable ring, 2, 3 – rigid plate; *max mesh size* – 0.2 mm

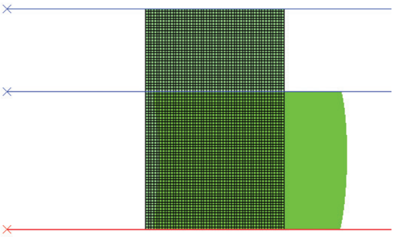
Fig. 4. Deformation of the ring for $\mu = 0.07$, $h_1 = 5$ mm

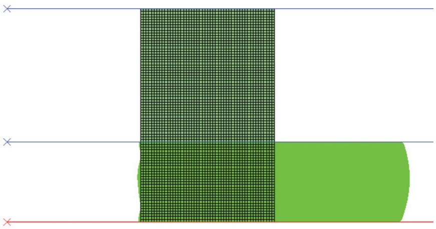
Fig. 5. Deformation of the ring for $\mu = 0.07$, $h_1 = 3$ mm

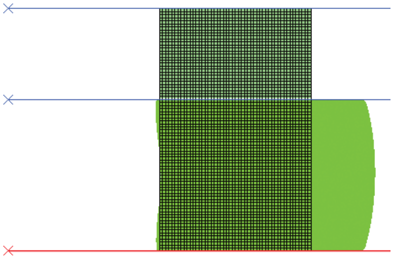

Fig. 6. Deformation of the ring for $\mu = 0.12$, $h_1 = 5$ mm

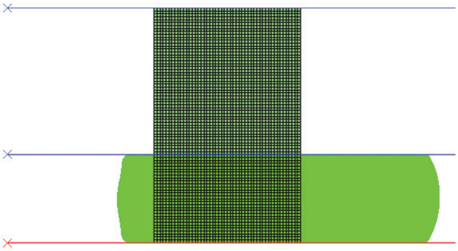

Fig. 7. Deformation of the ring for $\mu = 0.12$, $h_1 = 3$ mm

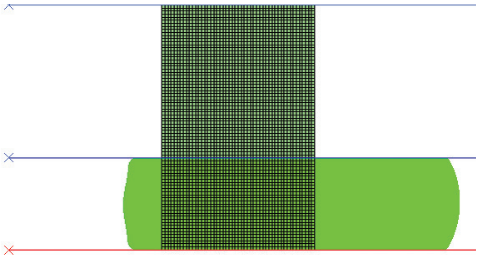

Fig. 8. Deformation of the ring for $\mu = 0.577$, $h_1 = 5$ mm

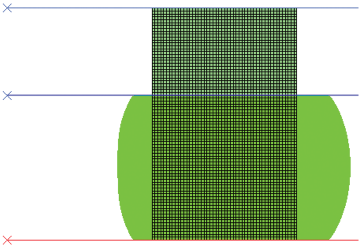

Fig. 9. Deformation of the ring for $\mu = 0.577$, $h_1 = 3$ mm

In Figs. 10–15, distributions of equivalent plastic strain are shown (PEEQ) according to formula (9). As it can be clearly seen, there is a strong heterogeneity of deformation at high strain values and coefficients of friction (Fig. 15, $\mu = 0.577$). The friction coefficient value $\mu = 0.577$ is the value at which stress reaches the value of $\sigma_p / \sqrt{3}$ and the material is adhered to the anvil.

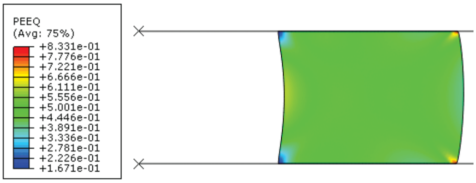

Fig. 10. Distribution of equivalent plastic strain (PEEQ); $\mu = 0.07$, $h_1 = 5$ mm

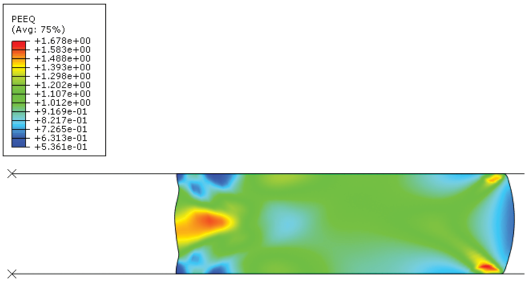

Fig. 11. Distribution of equivalent plastic strain (PEEQ); $\mu = 0.07$, $h_1 = 3$ mm

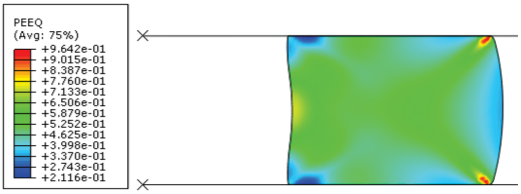

Fig. 12. Distribution of equivalent plastic strain (PEEQ); $\mu = 0.12$, $h_1 = 5$ mm

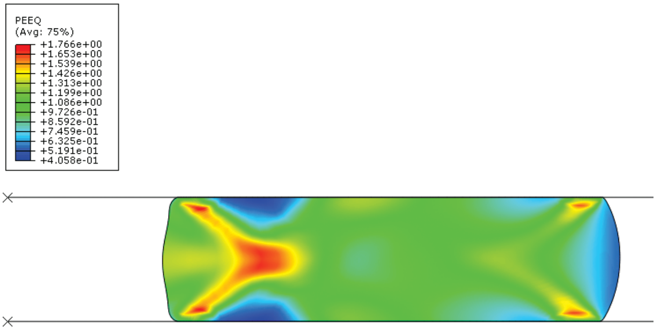

Fig. 13. Distribution of equivalent plastic strain (PEEQ); $\mu = 0.12$, $h_1 = 3$ mm

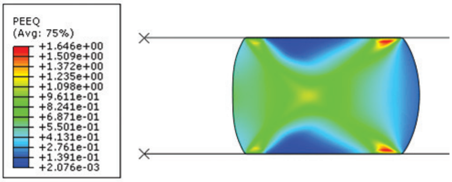

Fig. 14. Distribution of equivalent plastic strain (PEEQ); $\mu = 0.0577$, $h_1 = 5$ mm

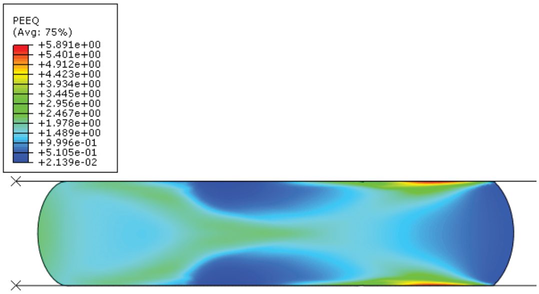

Fig. 15. Distribution of equivalent plastic strain (PEEQ); $\mu = 0.577$, $h_1 = 3$ mm

5. Comparison of calculation results and experiments

In order to verify the results of calculations performed in the ABAQUS software, experimental studies on the rings with identical dimensions as in the FEM analysis were carried out. The upsetting process was performed on the anvil with properly prepared surfaces and applied lubrication, which allowed for obtaining different coefficients of friction.

5.1. Changes of the outer diameter

Fig. 16 shows the relative changes of the internal diameter of the ring as a function of the height reduction computed using the FEM analysis (solid line). On the graph, experimental points marked by different colours were also plotted. The measurement points corresponding to upsetting on the smooth anvils without lubricant (blue marks) are best suited to the curve corresponding to the friction coefficient of 0.12. Red points – which correspond to upsetting on the smooth lubricated anvils – best fit to the curve corresponding to the friction coefficient μ = 0.07. As controls, upsetting on the anvils grooved was also carried out (recommended by the CIRP, ICFG and INOP). The results of measurements (green marks) lie on the curve corresponding to the maximum coefficient of friction μ = 0.577.

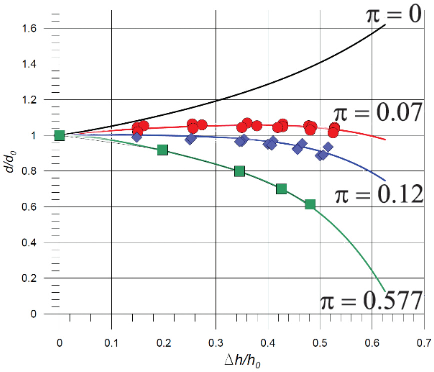

Fig. 16. Results of measurements of the rings' internal diameters after upsetting (red marks – anvils without lubrication, blue marks – anvils lubricated) on the background of the lines for fixed values of the friction coefficients

5.2. Shape of the samples after upsetting

To analyze the cross-sectional shape of the ring after upsetting, three characteristic samples with height reduced to $\Delta h = h_0 = 3/8$ and the coefficients of friction respectively 0.07, 0.12 and 0.577 have been chosen. Appearance of the cross section of the cut sample is shown in Figs. 17a–19a. For comparison, in Figs. 17b–19b, sections obtained by the FEM analysis are presented. It is apparent from the drawings that there is a strong resemblance to the actual shape obtained in the FEM analysis.

a) b)

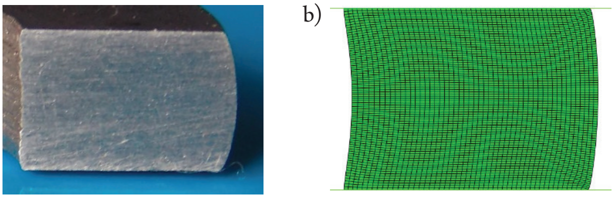

Fig. 17. Comparison of the shape for μ = 0.07, h_1 = 5 mm: a) the actual cross-section, b) the shape obtained from the FEM analysis

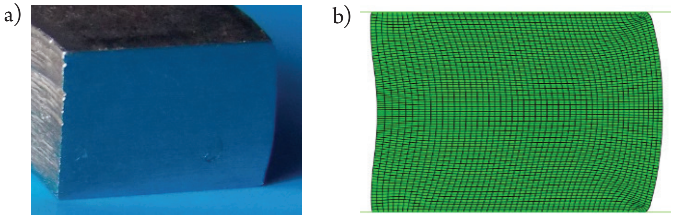

Fig. 18. Comparison of the shape for $\mu = 0.12$, $h_1 = 5$ mm: a) the actual cross-section, b) the shape obtained from the FEM analysis

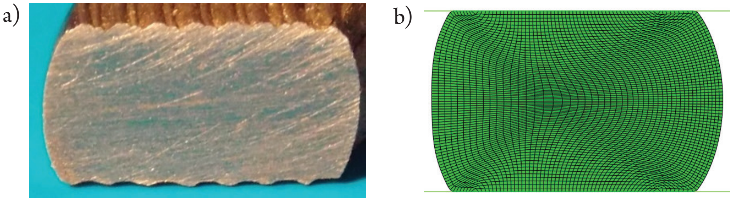

Fig. 19. Comparison of the shape for $\mu = 0.577$, $h_1 = 5$ mm: a) the actual cross-section, b) the shape obtained from the FEM analysis

In order to compare the dimensions of the cross sections obtained in the FEM analysis with the actual measuring, 12 evenly spaced points have been selected along the *Y*-axis as in Fig. 20. The values of the *X*-coordinate obtained in the FEM analysis have very similar values in many points. The largest differences in the *X* coordinate do not exceed 5%.

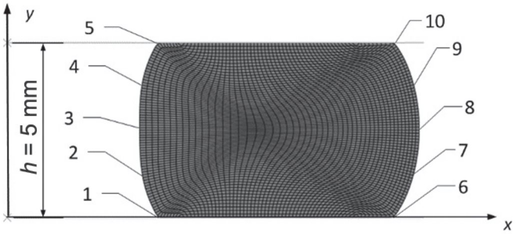

Fig. 20. Selected measuring points of the shape coordinates after upsetting the sample

6. Summary

The article presents the results of a computer simulation of a ring upsetting process using FEM. ABAQUS software was used. The calculations were performed for fixed dimensions of the rings and particular material for which the hardening curve was determined experimentally. Thus, relationships between different values of friction coefficients and such parameters as inner diameter, distribution of equivalent strain and upsetting force were determined. It can be clearly seen that there is a strong influence of friction conditions on the heterogeneity of deformation (Figs. 10–15) and, in particular, on the nature of changes of internal diameters (Figs. 4–9). Experimental upsetting studies were performed using smooth and rough anvils

– with and without lubrication – which caused changes in friction conditions on the contact surfaces. There was a good correlation between the actual and FEM – calculated shapes of the deformed rings (Figs. 17–19). In addition, the resulting dimensions of upsetting rings have been shown in the background of theoretical relations of diameters $d = d_0$ depending on the height changes $\Delta_h = h_0$ (Fig. 16). The experimental points fit well with their corresponding theoretical curves, which confirms the possibility of using the presented method of ring upsetting to determine friction coefficients' values.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017

MECHANICS

DOI: 10.4467/2353737XCT.17.183.7291

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The conditions for thermographic testing of thermal power engineering installations

Uwarunkowania termowizyjnych badań instalacji energetyki cieplnej

Abstract

Thermographic cameras are becoming increasingly popular in all kinds of diagnostic testing aiming to assess the technical state of thermal power engineering machinery, equipment and installations. The cameras provide thermograms that enable identification of various irregularities, including thermal bridges. However, it can be observed that their accuracy and reliability depend substantially on the conditions in which tests are carried out. Industrial thermographic testing, especially in thermal power engineering, is one of the most difficult procedures. Apart from the advantages of this particular technique, this paper presents an analysis of the effect of the conditions in which tests are performed on the obtained results. Attention is drawn to parameters characterizing the environment and the tested element surface, such as emissivity, reflected temperature, distance between the camera and the object, air temperature, etc. The sources of errors in the testing and in the interpretation of thermograms are indicated. Methods are also presented that enable elimination of irregularities, which improves the accuracy of the final results.

Keywords: engineering installations, thermographic testing, thermogram, emissivity, reflected temperature

Streszczenie

Kamery termowizyjne są coraz częściej wykorzystywane w różnego rodzaju badaniach diagnostycznych mających na celu ocenę stanu technicznego maszyn, urządzeń i instalacji eksploatowanych w energetyce cieplnej. Uzyskiwane za ich pomocą termogramy pozwalają identyfikować różne nieprawidłowości, a także mostki termiczne. Można jednak zauważyć, że w badaniach termowizyjnych istotne znaczenie mają warunki, w jakich są one przeprowadzane. Te przemysłowe, w tym szczególnie w energetyce cieplnej, należy zaliczyć do trudnych. W artykule, obok wskazania zalet takich badań, przedstawiono analizę wpływu warunków, w jakich są one realizowane. Zwrócono uwagę na parametry charakteryzujące otoczenie i powierzchnię badanego elementu, jak np.: współczynnik emisyjności, temperatura odbicia, odległość kamery od obiektu, temperatura powietrza. Wskazano na źródła błędów podczas wykonywania tych badań i interpretacji termogramów. Podano sposoby eliminacji nieprawidłowości, co zwiększa dokładność wyników końcowych.

Słowa kluczowe: instalacje energetyczne, badania termowizyjne, termogram, emisyjność, temperatura odbicia

1. Introduction

Thermal power installations used in the power sector important facilities such as power plants, combined heat & power plants and industrial plants, as well as boiler rooms in central heating and hot tap water preparation systems, enable conversion of primary (mainly fossil fuel) energy to a more convenient and usable form transferred as the working medium (typically: saturated or superheated steam or hot water) to appropriate receivers. This is where further energy conversion or transformation takes place. Adopting such a perspective, a thermal installation is understood as a system of various devices connected to each other (e.g. boilers, deaerators, heat absorbers and accumulators), machines (e.g. steam turbines, pumps, fans) and pipes (pipelines), together with appropriate fittings (including monitoring, control and diagnostic systems). Assuming that all subassemblies operate correctly, these elements make it possible to realize thermal technology processes [1, 2] with an efficiency level corresponding to the current state of the art. It should be noted, however, that in thermal power installations the energy conversion efficiency is limited by different factors, such as:

- specific energy conversion quality (which is specific to the applied cycle, e.g. the Clausius-Rankine cycle, and referred to as the cycle theoretical efficiency),
- specific efficiency of the thermal installation assemblies/components mentioned above,
- energy losses occurring during the process of both energy conversion and transfer.

The first two causes result, respectively, from the character of the working medium thermodynamic transitions and from technological, structural and operating characteristics of the assemblies used in the thermal installation. The energy losses (in this case: in the form of thermal losses) occur mainly during the equipment operation and are related to the heat exchange between the elements and the environment. Heat escapes through external surfaces and thermal bridges [3–7]. Even though external surfaces are usually insulated, heat losses will occur anyway because, as it is commonly known, perfect insulation does not exist (e.g. in the case of boilers, rarely considered for this case [7]). Moreover, the losses may be increased, for example, due to possible irregularities arising from the insulation assembly or because of the insulation material crumbling and ageing [5, 7]. Such effects can be classed as a kind of thermal bridges defined in [3, 5–7] as assembly- or operation-related ones. Another type includes structural thermal bridges [3–7], which are important due to the amount of heat losses they generate [5, 7]. It should be noted, however, that identification of all these thermal bridges in thermal power engineering is still incomplete (which is not the case in the building industry [8, 9]). Consequently, they are not estimated adequately. Sometimes, thermal bridges are even omitted in calculations. It may additionally be stated that such omission (though affecting the accuracy of the assessment of their impact on heat losses) is possible in the case of thermal bridges existing in a given device structure from the very beginning (which results from the need to ensure appropriate operation or control of operating parameters for example). But it can be difficult for those arising later on (e.g. due to operating irregularities). The former are usually „known" and often visible, such as elements of the pipeline support or hanging, measuring stub pipes, non-insulated inspection hatches, etc. But they can also be invisible elements embedded in the insulation material (usually adhering or being permanently connected to the insulated surface), e.g. supports of the insulation protective mantle, the insulation grips, stop blocks of the fastening devices, etc. [3, 6]. The latter, i.e. thermal blocks that may appear later on, are usually invisible under the protective mantle, e.g. the insulation material displacement (dropping, sagging), the occurrence of dampness, deformation, etc. They involve discontinuities and result in changes in the insulation thickness and/or air voids [3, 6].

The thermal installation energy losses are mainly the effect of the thermal insulation defects resulting not only from errors made at the insulation design, selection and production stage but also from irregularities appearing later on, during operation. Therefore, the following tasks are of great importance in power engineering:

- application of such a calculation methodology that enables economically efficient selection of the insulation thickness, which may produce savings for the company,
  This is made easier by the regulation now binding in Poland [10], under which the decision concerning the temperature of the insulation external surface is left to the operator. It may be added that until 2013 the only condition was to satisfy the occupational health and safety requirements. Pursuant to the repealed act [11], the temperature mentioned above could reach as high as 60°C (the two acts are compared in [12]),
- inspection of thermal installations to assess the current technical state of thermal insulation and identify thermal bridges, and, if necessary, performance of repair works (preferably – taking account of economic determinants of the enterprise),
- systematic assessment of the technical state of thermal installations with respect to heat loses they generate (in order to ensure systematic prevention of an uncontrolled rise in the losses and means of minimizing them).

Investment aiming to reduce energy losses is defined as actions taken in thermo-modernization. As a rule, these actions are the simplest method of improving energy efficiency, and they are usually associated with the possibility of making savings in energy needed to satisfy own needs of buildings. This also concerns thermal power installations in the industry. Activities related to thermo-modernization have become a popular investment in many Polish power engineering companies. The activities are conditioned by legal regulations on energy efficiency, which make the binding requirements for enterprises even stricter. One of such acts in Europe is the Directive of the European Parliament and of the Council of 2012 [13]; in Poland: the Act of 2016 [14] and the regulation and announcement [15, 16] on the tender for the selection of projects aimed at improving energy efficiency and on the detailed list of energy efficiency improving projects, respectively. To supplement the above, it should be added that considering the issues discussed herein, apart from the need to meet the legal requirements, an important factor is the awareness of the savings resulting from this type of investment and of the short periods of the investment return. Other essential effects are an improvement in the machinery and equipment efficiency and reduction in the negative impact on the environment.

In order to determine energy losses in operated thermal power installations and then select the appropriate and economically justified thermo-modernization actions, it is indispensable to perform the testing mentioned above. Thermographic testing seems to be a favourable option here, as it enables identification of places where increased heat losses occur, both through the facility insulated surfaces and through thermal bridges. However, identification only, i.e. a quantitative assessment of these places, is insufficient. In order to make an exact assessment of heat losses generated in them, it is also necessary to ensure an adequate accuracy of the testing, which is discussed further below. The elimination of errors in the use of thermographic cameras (in difficult industrial conditions of the measurement) and a correct interpretation of the results the cameras provide come down to an appropriate quantitative assessment enabling a correct estimation of the heat losses.

2. Principles of thermographic testing of thermal power installations

Any tests performed in industrial conditions, especially in conventional power plants with coal-fired boilers, have to be classed as difficult. This is due not only to the usually high temperature and pressure parameters of the working medium, but also to the fouling of the surfaces, the dust content, moisture or aggressiveness of the environment, bad lighting or lack thereof, the negative impact of neighbouring facilities, poor access, etc. These factors sometimes have an essential effect on the results of measurements made by means of thermographic cameras. Attention will be drawn to some of them and rules will be given that will enable a correct measurement, using the cameras mainly to check the thermal quality and "thermal tightness" of the thermal power facility insulation and to identify thermal bridges.

Thermographic testing makes it possible to measure the surface temperature of a device. It is known that each body with a temperature higher than absolute zero (0 K = –273.15°C) emits thermal radiation (invisible to the human eye but being felt through the skin as heat). Thermographic cameras are used to make measurements of the radiation in the range of longer wavelengths (from about 0.9 μm to ~14 μm), recording thermal radiation emitted by the „observed" objects. Based on that, images can later be created that map the temperature distributions of the „viewed" surfaces. This is possible owing to measuring transducers (detectors) installed in thermographic cameras and to specialist software that improves the capability and quality of the camera operation. It can be added that in the images specific colours are assigned to specific temperatures. A scale is created, in which the palette of colours from a given thermogram is presented together with corresponding values of temperature. It should also be noted that, unfortunately, the radiation detected by the camera includes direct radiation and radiation reflected by objects in the surrounding space, which may result in further errors. Nevertheless, tests made by means of infrared thermal imaging cameras exhibit a number of advantages over other methods, like point (contact) measurements for example. The infrared thermography is widely used in various research areas. This statement is confirmed by references [17–22], review papers [23, 24] and works related to the assessment of this method [25–27]. In particular, the favourable features include as follows (for this method):

- contactlessness of the temperature measurement of facilities to which access is difficult or which are very distant (e.g. facilities located beyond the direct reach of the inspection team member(s), or positioned close to power engineering equipment or live electrical appliances/facilities),

- determination of the temperature distributions (fields) even for large areas, practically in many places at the same time, which shortens the testing time,
- a chance to identify places characterized by a more intense heat exchange (fast detection of thermal bridges).

In order to make a correct measurement by means of a thermographic camera and interpret the results obtained therefrom properly, special account has to be taken of the following quantities in every case:

- parameters characterizing the impact of the tested element surface – emissivity and reflected temperature in the first place,
- parameters characterizing the impact of the surroundings: ambient temperature, air humidity, air flow velocity, distance from the object and the measuring angle.

The parameters included in the first group mentioned above are analysed below.

Thermal radiation of every body is characterized by emissivity, absorptivity and reflectivity. When it comes to thermographic cameras, emissivity is one of the most important parameters that affect the quality of measurements. Correct results cannot be obtained unless the tested surface emissivity is known (estimated). The parameter is defined as the ratio between radiation emitted by the surface, here a real body, and radiation emitted by a black body. Its values are included in the range from 0 (for white bodies, emitting no thermal radiation and reflecting it completely) to 1 (for black bodies, whose thermal radiation is the strongest and which absorb the entire radiation falling onto them). Therefore, it may be stated that in the case of bodies whose surface is characterized by a high emissivity value, the radiative heat transfer is more intense. At the same time, as practice shows, under such conditions, the measurement is easier and gives more correct results. It is more difficult to perform measurements if the surface is shiny, rough or dirty. In terms of thermography, the facts presented above mean that:

- if the tested object temperature is higher than ambient, setting emissivity in the thermographic camera (if possible) to a value higher than the actual one, e.g. due to an estimation error, results in a temperature reading which is lower than actual (if, on the other hand, emissivity is set to too low a value, the reading will be inflated),
- if the tested object temperature is lower than ambient, inflating emissivity (due to reasons as above) results in temperature readings higher than the actual one (for too low emissivity values, on the other hand, temperatures will be understated),
- at lower emissivity values, the share of reflected radiation for the tested material is higher; consequently, it is more important to establish the correct value of reflected temperature.

In the case of typical materials, tabularized values can be used to find the tested object surface emissivity value. The values for some materials, including those used in industry (e.g. as a coating or protective layers of various devices) are listed in Table 1 [28, 29].

Table 1. Emissivity values for selected materials typically used for construction of industrial facilities

Material		Temperature, [°C]	Emissivity
Aluminium	polished	50–100	0.04–0.06
	with a rough surface	20–50	0.06–0.07
	highly oxidized	50–500	0.2–0.3
Sheet metal	zinc	50	0.20
	shiny zinc	30	0.23
	nickel steel	20	0.11
	rolled steel	50	0.56
Cast iron		50	0.81
Copper	polished	50–100	0.02
	oxidized	50	0.6–0.7
Pure polished silver		200	0.02
Oil paint		20	0.94
Enamel paint		20	0.85–0.95
Porous red brick		20	0.88–0.93
Gypsum		20	0.8–0.9
Paper	white	20	0.7–0.9
	black unglazed	20	0.94
Soot		20–400	0.95–0.97
Water layer on a metal surface		20	0.98

However, it should be noted that, in the industry, the surfaces of objects tested with the use of thermography are often fouled or covered with dust, and their temperature differs from values for which emissivity is given in tables. In such cases, the most accurate method is to determine the temperature values by own means. The testing procedure is facilitated by special tapes or labels (cf. Fig. 1), with a known constant emissivity value – $\varepsilon_p = 0.95$ – corresponding to a given temperature range. The tapes are characterized by low thermal resistance.

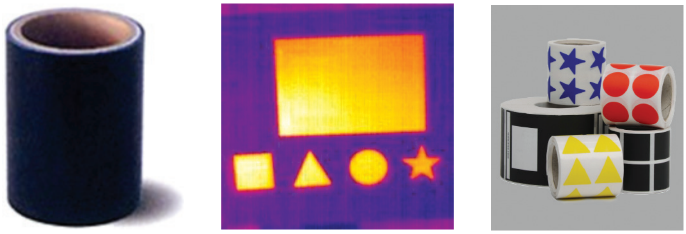

Fig. 1. Example tapes (HB-250, IR-ID Labels) with a constant emissivity value

A fragment of the tape shown in Fig. 1 should be placed on the tested object in a relevant inspection point and time should be allowed to let it heat up to the temperature of the surface. Setting the emissivity value in the thermographic camera to $\varepsilon_k = \varepsilon_p = 0.95$, the temperature measurement is performed at the place of the tape location. After the tape is removed, the emissivity value should be adjusted so that exactly the same temperature is obtained on the surface. Example thermograms obtained by means of this procedure are presented in Fig. 2 (a FLIR E60 infrared thermal imaging camera was used).

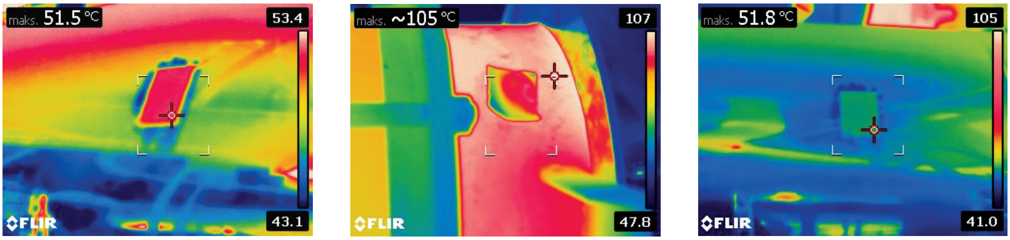

Fig. 2. Pipeline surface temperature measurement using tape HB-250

The appropriate emissivity value to be set in the thermographic camera can be determined to know the tested object surface temperature measured by means of a contact thermometer. The temperature in the inspected place should be checked using a thermographic camera in which the emissivity setting should be altered gradually until the camera reading is equal to the value measured by the thermometer.

The value of the tested object surface emissivity can be determined using the following relations [5]:

$$\dot{Q}_r = C_{1-2}\varphi A\left(T_1^{\,4} - T_2^{\,4}\right) \tag{1}$$

$$C_{1-2} = \frac{5{,}67\cdot 10^{-8}}{\dfrac{1}{\varepsilon_1} + \dfrac{A_1}{A_2}\left(\dfrac{1}{\varepsilon_2} - 1\right)} \tag{2}$$

where:

- A – radiating surface area, m^2,
- A_1, A_2 – radiating surface area 1 and 2 with temperatures T_1 and T_2, respectively, m^2,
- C_{1-2} – radiation factor, W/(m^{2}K^4),
- $\dot{Q}_r$ – thermal energy exchanged between bodies due to radiation (radiant exchange), W,
- T_1 – surface temperature of the more heated body, K,
- T_2 – surface temperature of the less heated body, K,
- ε_1, ε_2 – emissivity of surface A_1 and A_2, respectively,
- φ – angle factor.

For $A_1 << A_2$ formula (2) can be simplified to the following form:

$$C_{1-2} = 5{,}67\cdot 10^{-8}\cdot \varepsilon_1 \tag{3}$$

If the tested object surface temperature is measured by means of a thermographic camera, a relation can be written using formulae (1) and (3), where $T_1 = T_{p(k)}$, $T_2 = T_d$, and $\varepsilon_1 = \varepsilon_k$:

$$\frac{\dot{Q}_r}{A\varphi} = 5{,}67 \cdot 10^{-8} \cdot \varepsilon_k \left(T_{p(k)}^{\ 4} - T_d^{\ 4} \right) \tag{4}$$

where:

- T_d – camera detector temperature, K,
- $T_{p(k)}$ – tested surface temperature measured by the thermographic camera, K,
- ε_k – emissivity set in the thermographic camera.

Using the surface known temperature measured by the contact thermometer, relation (4) can be expressed in the following form (where $T_{p(k)} = T_p$ and $\varepsilon_k = \varepsilon_p$):

$$\frac{\dot{Q}_r}{A\varphi} = 5.67 \cdot 10^{-8} \cdot \varepsilon_p \left(T_p^{\ 4} - T_d^{\ 4} \right) \tag{5}$$

where:

- T_p – tested surface real temperature measured by the contact meter, K,
- ε_p – emissivity of the tested object surface.

Comparing relations (4) and (5), it is possible to define the formula for the tested surface emissivity:

$$\varepsilon_p = \varepsilon_k \frac{T_{p(k)}^{\ 4} - T_d^{\ 4}}{T_p^{\ 4} - T_d^{\ 4}} \tag{6}$$

The effect of a wrong value of the tested surface emissivity on the results of the surface temperature measurement obtained by means of a thermographic camera is shown in Fig. 3 [5]. The tested facility was a steam pipeline whose insulation layer in the controlled area was covered with a protective mantle made of zinc sheets. The neighbouring sheets are characterized by a different technical state (surfaces with different oxidation and fouling degrees).

A VIGO *V-20 II* thermographic camera was used for the testing. The camera has a constant emissivity value adopted for the conversion of quantities – $\varepsilon_k = 0.95$. The insulation mantle temperature was measured in selected points using a *TES 1312A Limatherm* thermometer. In Fig. 3 it can be observed that the two methods produced different results. The lower values obtained by means of the thermographic camera, compared to those measured by the thermometer with a contact probe (in zones corresponding to each other they are, respectively, from ~35°C to ~45°C and from ~50°C to ~59°C), at ambient temperature of about 27°C, prove that the emissivity value set in the camera was inflated in this case (which in fact complies with the remark on thermography made above).

The obtained data made it possible, using relation (6), to estimate the emissivity value for the surfaces shown in Fig. 3. They are as follows: $\varepsilon_{(1)} = 0.63$; $\varepsilon_{(2)} = 0.69$; $\varepsilon_{(3a)} = 0.73$; $\varepsilon_{(3b)} = 0.83$ (the marking of respective surfaces is included in the subscripts, in brackets). It should be noted that the surface emissivity decreases as the surface temperature gets lower. Naturally, this also results from relation (6). It may also be added that a clean surface of the power engineering facility insulation protective mantle means smaller heat losses due to the lower value of emissivity.

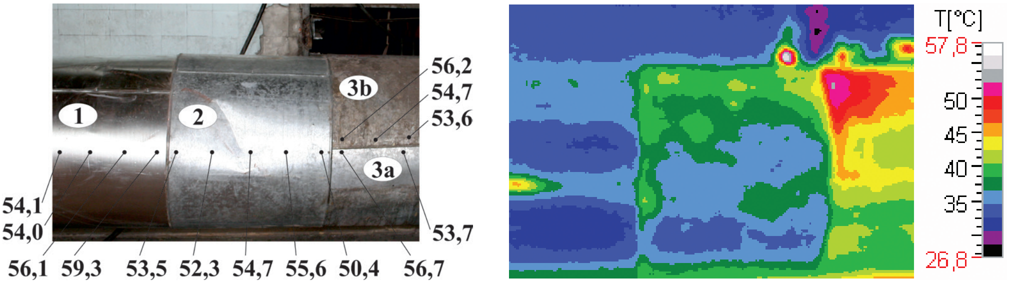

Fig. 3. Results of temperature measurements of the protective mantle of the steam pipeline insulation made by means of a contact thermometer (left side – points denote inspected places and the values corresponding thereto) and a thermographic camera (right side): 1 – new part (relatively clean), 2 – part with a low degree of oxidation (relatively clean), 3a and 3b – parts with a higher degree of oxidation, with a different fouling degree (3a – relatively clean, 3b – heavily fouled)

Another essential element of thermographic testing is an exact determination of the parameter defined as the reflected temperature compensation (RTC), which, apart from emissivity, can also be set manually in the applied thermal imaging camera. Generally, if there are no sources of interference (radiation emitters) in the vicinity of the tested facility, the reflected temperature is equal to the temperature of the surroundings, which can be measured using a thermometer. In industrial conditions, however, the environment of the testing usually includes elements of operating equipment or installations which are sources of radiation. In such a case, the temperature has to be measured using e.g. the Lambert radiator, which reflects radiation equally in all directions. The temperature measured on it using a thermographic camera is the sought value. A piece of crumpled and then smoothed out aluminium foil is commonly used for this purpose. The foil is placed on the tested object and its temperature is measured using a thermal imaging camera, setting emissivity to $\varepsilon_k = 1$. After the temperature value determined in this way is entered into the camera as the RTC, the planned testing can be performed (for emissivity specific to the tested object surface). Fig. 4 presents the practical method of the reflected temperature value determination.

The reflected temperature measurement is also absolutely necessary in on-site field inspections (in thermal power engineering this concerns e.g. inspections of the technical state of above-ground district heating or process steam pipelines, including the insulation quality and identification of thermal bridges [3, 6]). A cloudless sky emits thermal radiation with the temperature of 50–60°C, whereas sunlight reaches the temperature of about 5500°C. Due to that, the reflected temperature during measurements performed in such conditions is often lower than 0°C. Therefore, outdoor measurements should best be carried out early in the morning or under cloudy skies. If for technical reasons this cannot be done, the mean radiant

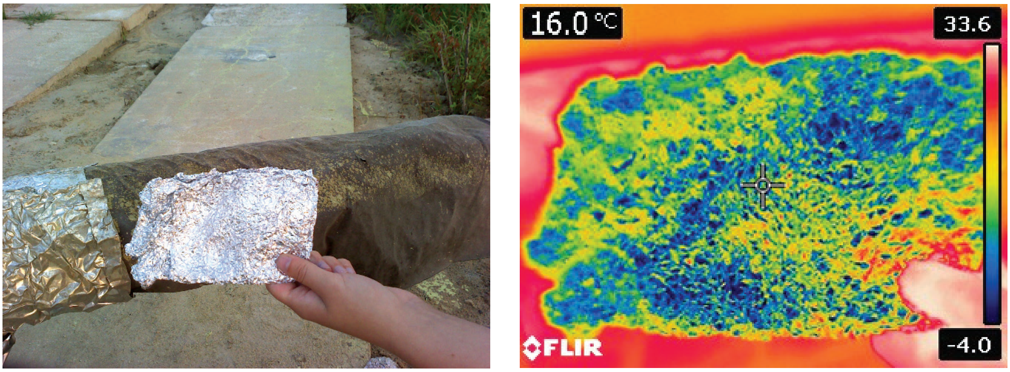

Fig. 4. RTC value determination using an equivalent of the Lambert radiator (a piece of crumpled and then smoothed out aluminium foil)

temperature of the sky (the sky temperature) has to be taken into consideration. Its value in the entire spectrum of thermal radiation, for the vertical plane in Poland, can be calculated using the empirical formulae presented below [30]:

- for a cloudless sky:

$$t_r = -19.04 + 1.33 \cdot t_e \tag{7}$$

- for a completely overcast sky:

$$t_r = -0.92 + 1.14 \cdot t_e \tag{8}$$

where:

t_e – air temperature, °C,
t_r – mean radiant temperature of the sky, °C.

Fig. 5 presents a thermogram obtained during an inspection of district heating pipelines, which illustrates an apparent occurrence of a negative temperature value on the tested objects due to the sky temperature reflection. This is the effect of the impact of a cloudless cold sky. It can be „seen" by a thermographic camera, which automatically expands the measuring range (the temperature scale) and changes the arrangement of colours in the thermogram.

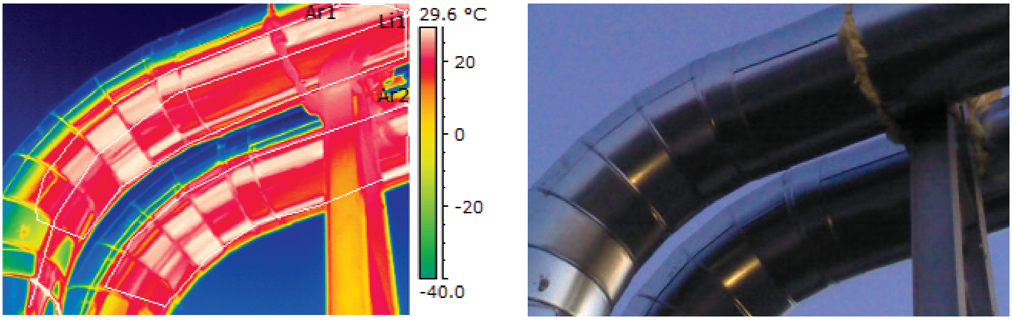

Fig. 5. Thermal images of a district heating pipeline

Conditions in the industries where the thermographic research are conducted, cause that accuracy of obtained thermograms are less dependent on exact determination of environmental parameters, i.e.: ambient temperature, the air humidity and flow velocity, and also distance and angle at which measurements are performed (in comparison to previously mentioned parameters, i.e. emissivity and reflected temperature). However, some of these parameters have major influence for determination of estimated heat losses, because their value is depend, among others, on:

- accuracy of ambient temperature determination,
- correct determination of the heat transfer coefficient, the value of which is substantially dependent on the air flow velocity.

The presented principles were applied while performing thermographic tests of an OP-140 power boiler. The aim of the testing was to identify the boiler thermal bridges and find the temperature of their surface and of the boiler other regular surfaces (walls). Successful completion of these tasks made it possible to assess the boiler heat losses, including those generated by thermal bridges [7]. Example thermograms, together with photographs of the inspected zones, are shown in Fig. 6 (for one of the boiler side walls) and Fig. 7 and Fig. 8 (for the boiler selected thermal bridges). The tests were performed using a FLIR E60 infrared thermal imaging camera for the boiler near-nominal continuous rating between 08:00–15:00 hours. At the same time, the parameters of the surroundings (here, the boiler room air) were measured, e.g. temperature, which varied depending on the boiler height from about +12°C (+0.00 m level) to about 40°C (+35.00 m level), and relative humidity, which totalled about 40%.

It should be added that Figs. 6–8 include areas limited by dashed lines, for which the mean value of the surface temperature was estimated using the software of the applied thermographic camera (the knowledge of the temperature is indispensable for determination of heat losses).

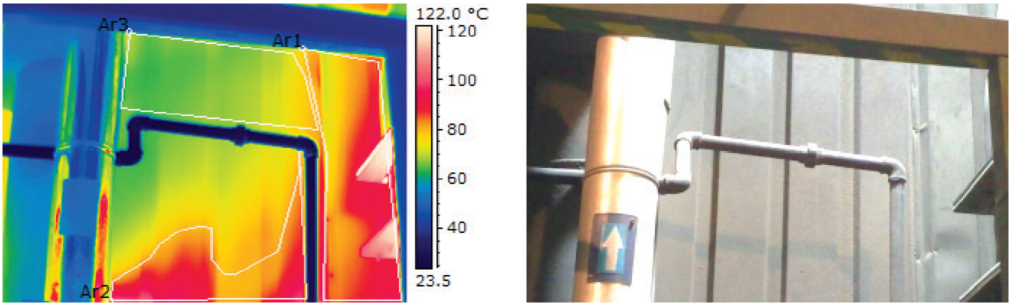

Fig. 6. Thermogram and photograph of the OP-140 boiler regular surface (wall)

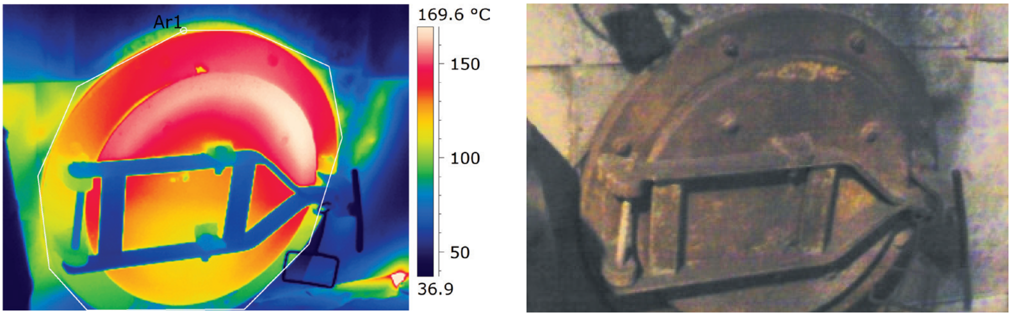

Fig. 7. Thermogram and photograph of the OP-140 boiler structural thermal bridge (inspection hatch)

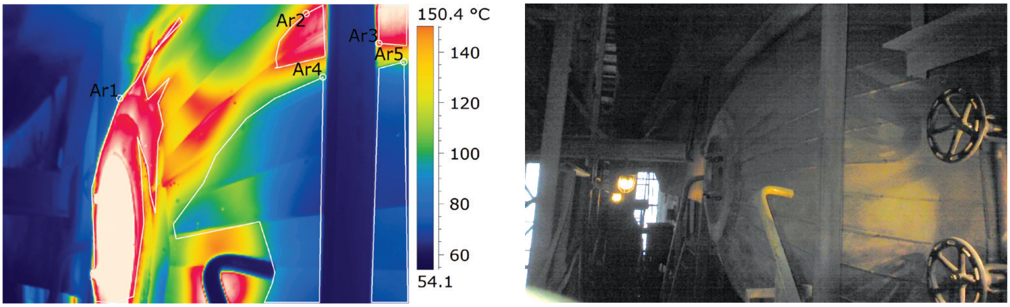

Fig. 8. Thermogram and photograph of the OP-140 boiler structural and assembly-related thermal bridge (inspection hatch of the boiler drum and displacement/irregularity thickness of insulation)

3. Concluding remarks

Thermographic testing is a good tool for thermal diagnostics of power engineering facilities. The advantages comprise the relative ease of performance, as well as the method non-invasiveness and the short time needed to obtain the measurement results and visualize them in an accessible way. This kind of testing is especially useful in areas such as:

- assessment of the technical state of thermal insulation, including detection of various defects thereof which may arise with time (e.g. thinning of insulation or its displacement, crumbling or dampness),
- identification of thermal bridges in the power engineering machinery, equipment and installations.

Using infrared thermal imaging cameras to measure the surface temperature of inspected power engineering facilities, for example for the purposes of estimation of heat losses, requires keeping adequate accuracy. In other words, the technique should produce reliable results. In order to eliminate possible errors, the necessary parameters should be determined correctly and then set in the thermographic camera. This especially concerns the values of the inspected surface emissivity and reflected temperature compensation (RTC). It is also important to select appropriate conditions for the measurement performance. For example, if the measurements are made in the power plant boiler or engine rooms (turbines hall), the sources of radiation that might interfere with obtained results should be removed or, at least, their impact should be mitigated. For measurements of outdoor facilities, the favourable conditions are e.g. the night-time or early morning hours, a cloudy sky and no rain.

The results of the thermographic testing performed for the OP-140 boiler indicate that numerous places characterized by increased heat losses may arise in the thermal power engineering facilities. These places are invisible to the naked eye, but thermal imaging makes it possible to detect them. This may especially concern the power engineering machinery, equipment and installations with a long lifetime because, with the passing of time, the thermal insulation degradation and destruction accumulate and become more severe. However, heat losses in power engineering facilities may also be generated by their thermal bridges. For now, the identification of thermal bridges is still incomplete and thus their effect cannot be taken into account to a satisfactory extent. Therefore, works carried out in this direction, with the use of infrared thermal imaging cameras, are fully justified. They will make it possible not only to prepare appropriate thermo-modernization actions but also develop better design solutions eliminating thermal bridges or mitigating the negative impact thereof. The actions will thus improve the energy efficiency of thermal power facilities and, indirectly, help to protect the natural environment.

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TECHNICAL TRANSACTIONS 10/2017
CZASOPISMO TECHNICZNE 10/2017
MECHANICS
DOI: 10.4467/2353737XCT.17.184.7292

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CFD simulations of hydrofoils for tidal turbines

Symulacje CFD profili turbin wykorzystujących pływy morskie

Abstract

Tidal energy might be extracted in a very similar way as the wind one by using turbines. However, due to environmental conditions, unsteady nature of tidal currents and wave activity, tidal turbines have to fulfill very demanding requirements. Such turbines might be structurally similar to wind turbines, but due to a different medium, the key issue is extracting tidal energy in the most effective way. This paper presents a way in which CFD tools may be used for selecting hydrofoil for tidal turbines.

Keywords: CFD, tidal turbine

Streszczenie

Energia pływów morskich może być pozyskiwana w podobny sposób jak energia wiatrowa. Jednakże ze względu na warunki środowiskowe oraz zmieniające się warunki pracy turbiny muszą spełniać bardzo wysokie wymagania. Mogą one być podobnie zbudowane jak wiatrowe, ale ze względu na inny rodzaj medium kluczową sprawą jest uzyskiwanie energii w najbardziej efektywny sposób. W referacie przedstawiono wykorzystanie narzędzi CFD do doboru odpowiedniego profilu łopat wirnika turbiny.

Słowa kluczowe: CFD, turbina wykorzystująca pływy morskie

1. Introduction

Demand for electrical power rises every year even due to a significant improvement of power efficiency. Increased power demand, if covered by traditional energy sources, will lead to enormous pollution. Therefore, renewable energy may be a solution. Except for wind, water and solar power, tidal energy is gaining more and more interest, and in comparison to wind power, it has higher energy density and predictability. Tidal energy may be extracted in a similar way as wind power. However, operating conditions, unsteady tidal currents and wave activity are the reasons why tidal turbines have to meet very high requirements. Another issue is a very high cost of their installation and maintenance. Tidal energy is a relatively young branch of renewable energy, but some practical applications already exist. Fig. 1 and 2 show examples of tidal turbine already in use.

Fig. 1. Fig. 1. A horizontal tidal turbine by ALSTOM

Fig. 2. Fig. 2. A tidal turbine installed in Northern Ireland

A lot of research has been conducted on tidal energy [1–3] for various tidal turbines: horizontal or vertical, floating on the sea surface or anchored to sea bed, or even with additional diffusers to increase turbine efficiency [4]. The design of a tidal turbine is still a challenge. The key issue is a proper selection of a hydrofoil and blade shape. Due to a different medium, blade element momentum (BEM) may not be directly implemented to a tidal turbine because of cavitation phenomenon which might be problematic to predict. Additionally, typical airfoils used in wind turbines may not extract tidal energy efficiently enough. Grasso F. [5] claims that efficiency of tidal turbines may be used in tailored hydrofoil. The Computational Fluid Dynamics (CFD) method, whose application in marine and wind turbine is presented in detail in work [6], brings a new quality to the design of tidal turbines. Design tools like CAE systems allow for investigating flow phenomena and evaluating load caused by water flow. This paper presents the use of CFD method for the evaluation of hydrodynamic efficiency of a typical airfoil. For three selected airfoils NACA 4418, 4416 and 4412, drag and lift forces were evaluated for the same Reynolds number.

2. CFD simulation of hydrofoils

The key factor for extracting energy is a hydrofoil and its hydrodynamic efficiency. For the evaluation of this factor, tools using BEM (blade element theory) like XFoil can be used. However, much more information can be obtained from CFD simulations, which use numerical solutions of flow governing equations. These are: continuity equation which is also called mass conservation equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U}) = S_M \tag{1}$$

and the momentum conservation equation:

$$\frac{\partial (\rho \mathbf{U})}{\partial t} + \nabla \cdot (\rho \mathbf{U} \times \mathbf{U}) = -\nabla p + \nabla \cdot \tau + F + \rho g \tag{2}$$

where τ is the stress tensor:

$$\tau = \mu \left(\nabla \mathbf{U} + (\nabla \mathbf{U})^T - \frac{2}{3} \delta \nabla \mathbf{U} \right) \tag{3}$$

The above equations might be completed with the energy equation, which is as follows:

$$\frac{\partial (\rho h)}{\partial t} - \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U} h) = \nabla \cdot (\lambda \nabla T) + \nabla \cdot (\mathbf{U} \cdot \tau) + \mathbf{U} \cdot F + S_E \tag{4}$$

where:

- ρ – is the fluid density,
- $\mathbf{U}$ – is the fluid velocity vector,
- p – is pressure,
- μ – is the fluid dynamic viscosity,
- S_M – is the momentum source,
- h – is the total enthalpy,
- S_E – is the energy source,
- λ – is the thermal conductivity, T – is the temperature,
- δ – is the Kronecker function,
- F – is external body forces,
- g – is the earth gravity.

Despite the fact that water current may reach relatively small velocity (pick value round 4 m/s), the flow around a hydrofoil is turbulent, which means that is unsteady and random by nature. Solving N-S equations (continuity and momentum conservation) in a general form for turbulent flows is very time consuming and inefficient. But it does not mean that turbulent flows are not able to be simulated. One of the approaches are Reynolds Averaging N-S equations (RANS), which define velocity as a mean value and fluctuations of this value. RANS define each value as a mean value and its fluctuations. In case of velocity we have:

$$u_i = \overline{u}_i + u_i' \tag{5}$$

where:

$\overline{u}_i$ – is the mean velocity value,

u_i' – is the fluctuating velocity, stands for velocity component.

After inserting Eq. (7) to N-S equations Eq. (1, 2), we obtain RANS equations:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho}{\partial x_i}(\rho u_i) = 0 \tag{6}$$

$$\frac{\partial \rho}{\partial t}(\rho u_i) + \frac{\partial \rho}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_i}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i u_j}\right) \tag{7}$$

The additional term which appears in Eq (7) $-\rho\overline{u_i u_j}$ represents the effects of turbulence (called Reynolds stress) and makes the set of Eq (6) and Eq (7) not closed, therefore it has to be modeled. A common method to close these equations is the Boussinesq hypothesis:

$$-\rho\overline{u_i u_j} = \mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\delta_{ij}\left(\rho k + \mu_t\frac{\partial u_k}{\partial x_k}\right) \tag{8}$$

and the use of turbulence models.

CFD simulations not only allow for gaining information about pressure or velocity distribution and turbulence intensity, but also for evaluating drag and lift forces which define the turbine efficiency. In this work, three airfoils NACA 4418, 4416 and 4412 were selected for CFD simulations. All the airfoils were examined at the same Reynolds number (approx. 100 000) for 2D angle of attack. The simulations were conducted in the Ansys CFX code with the following assumptions: the flow was turbulent (SST turbulence model), at steady state conditions with typical sea water properties at the depth of 10 m, the model was in thermal equilibrium, the airfoil had an ideal smooth surface and the water was not able to slip on the surface.

3. Object of study

The selection of a proper hydrofoil is not an easy task. A typical airfoil used in wind turbine may not be efficient enough and may cause cavitation, which is difficult to predict. Therefore, in this work three typical NACA airfoils were used in CFD simulation to estimate their lift and drag forces. Those were NACA 4418, 4416 and 4412 airfoils. Airfoil profiles were created based on coordinates extracted from available calculators [7] in the Creo Parametric system as 2D models.

All of them were tested in the same conditions, with the same grid size and for various values of angle of attack but for constant Reynolds number. During water flow over the hydrofoil, the lift force (L) is generated along with the drag force (D). The product of those two forces is a total force that appears on the turbine blade during fluid flow. Magnitude of both forces depends on the angle of attack. The ratio of lift coefficient to drag coefficient is one of the factors that describe hydrodynamic efficiency.

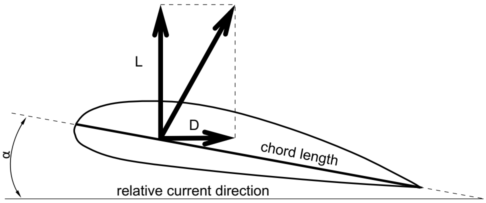

Fig. 3. Forces acting on a hydrofoil

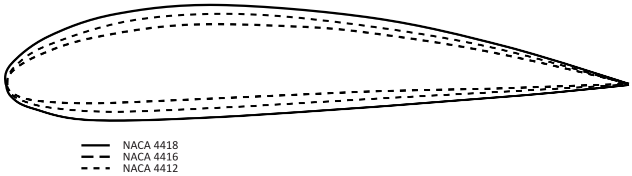

Fig. 4. Investigated airfoils

4. Results of CFD simulations

The CFD simulations were conducted in the Ansys CFX code, as 2D models. The simulations allowed for investigating velocity and pressure distribution as well as the lift and drag forces. The details of CFD results are presented in Figs. 5–7. These figures show velocity and pressure distribution for the angle of attack $\alpha = 0°$. Figures 8–10 show the ratio of lift coefficient to drag coefficient for various angles of attack, which range from –10° to 14°.

The lift and drag forces which were extracted from the CFD simulations, were approximated and presented in the figures below in the function of an angle of attack. The analysis of presented values shows that the last two profiles (4416 and 4412) reach much slower values of the CL/CD ratio than airfoil 4418, for which maximal values are between –0.5° to 6°.

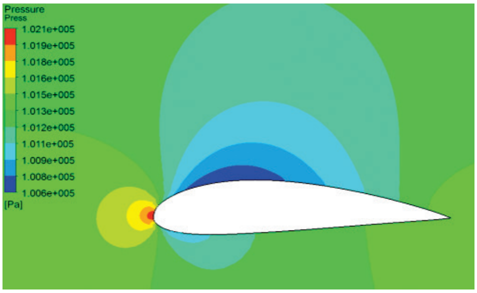

Fig. 5a. NACA 4418: pressure distribution

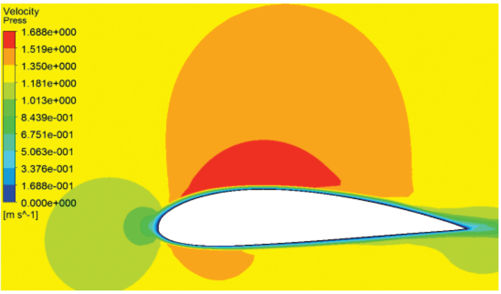

Fig. 5b. NACA 4418: velocity distribution

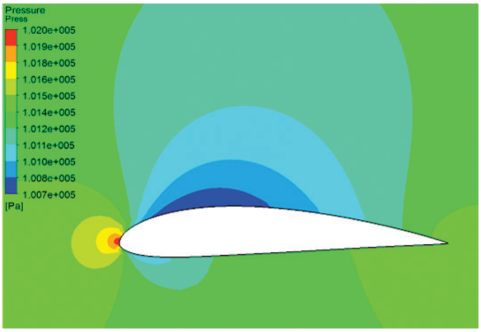

Fig. 6a. NACA 4416: pressure distribution

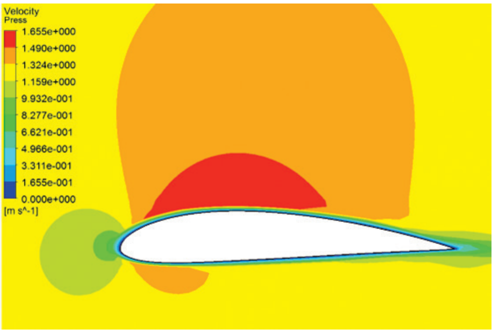

Fig. 6b. NACA 4418: velocity distribution

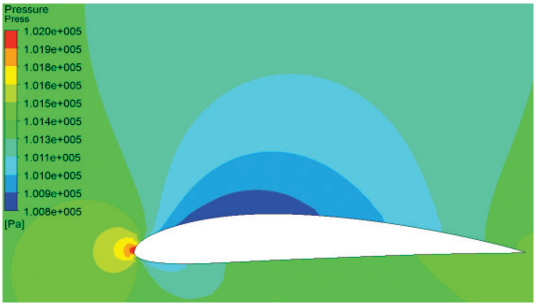

Fig. 7a. NACA 4412: pressure distribution

Fig. 7b. NACA 4418: velocity distribution

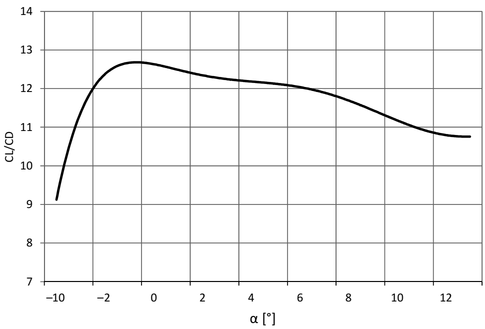

Fig. 8. CL/CD ratio for NACA 4418

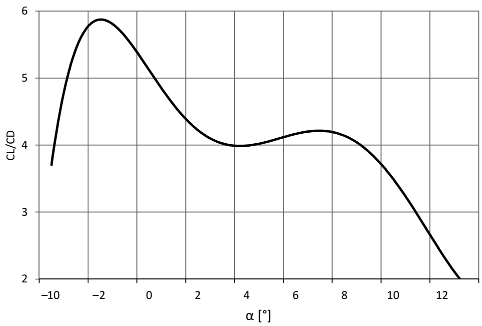

Fig. 9. CL/CD ratio for NACA 4416

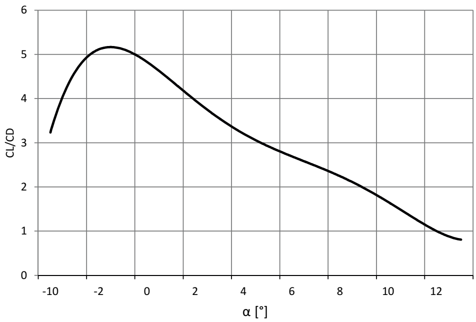

Fig. 10. CL/CD ratio for NACA 4412

5. Conclusions

Tidal energy is gaining more and more interest in recent years and, in comparison to wind power, is very attractive due to its power density and predictability. On the other hand, tidal turbines have to meet much stronger requirements and their design is still a challenge. Therefore, CFD tools seem to be very promising design tools for tidal turbines. They allow for evaluating pressure and velocity distribution, extracting lift and drag forces and even predicting cavitation. They can be also used for the prediction of total load that may appear during water flow. CFD simulations may also be used for the optimization of hydrofoils or creation of hydrofoils which allow for extracting tidal energy in the most efficient way.

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