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ADAPTIVE REUSE FOR NEW SOCIAL AND MUNICIPAL FUNCTIONS AS AN ACCEPTABLE APPROACH FOR CONSERVATION OF INDUSTRIAL HERITAGE ARCHITECTURE IN THE CZECH REPUBLIC

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ABSTRACT

The present paper deals with a problem of conservation and adaptive reuse of industrial heritage architecture. The relevance and topicality of the problem of adaptive reuse of industrial heritage architecture for new social and municipal functions as the conservation concept are defined. New insights on the typology of industrial architecture are reviewed (e. g. global changes in all European industry, new concepts and technologies in manufacturing, new features of industrial architecture and their construction and typology, first results of industrialization and changes in the typology of industrial architecture in post-industrial period). General goals and tasks of conservation in context of adaptive reuse of industrial heritage architecture are defined (e. g. historical, architectural and artistic, technical). Adaptive reuse as an acceptable approach for conservation and new use is proposed and reviewed. Moreover, the logical model of adaptive reuse of industrial heritage architecture as an acceptable approach for new use has been developed. Consequently, three general methods for the conservation of industrial heritage architecture by the adaptive reuse approach are developed: historical, architectural and artistic, technical. Relevant functional methods' concepts (social concepts) are defined and classified. General beneficial effect of the adaptive reuse approach is given. On the basis of analysis results of experience in adaptive reuse of industrial architecture with new social functions general conclusions are developed.

KEYWORDS

conservation; adaptive reuse; industrial heritage; social function; municipal function; new use; effective use.

RELEVANCY OF THE ADAPTIVE REUSE CONCEPT

According to present conditions of post-industrial cities' industrial infrastructure in the Czech Republic the industrial heritage architecture (including non-operating and ineffective industrial buildings as well as brownfields) demands today a new experimental level of conservation and use that means the level of conservation of industrial heritage architecture by the adaptive reuse approach.

Relevancy of the present research project is defined by actual problems of all industrial cities in the Czech Republic: e. g. importance of the new effective use of non-operating industrial buildings as well as industrial buildings with ineffective manufacturing, conservation of historical value of industrial objects, development of favorable city infrastructure etc. [1]. Moreover, it is reasonable to note local aggravating environmental situation because of industrial object that has negative influence on health improvement, psychic and emotional state of people, demographic

indices, including negative influence on social level of population, as well as economic and other indicators [1, 2]. It is important "to adapt" industrial heritage architecture for new effective functions with the conservation of historical and architectural value of all industrial heritage objects [2—5].

It is reasonable to emphasize, that the problem of adaptive reuse of industrial heritage as well as brownfields is so relevant nowadays [5, 6]. There are many organizations and institutions which are connected with this problem: scientific and research centers in the leading educational and scientific institutions, committees, specialized organizations with competent professionals, social groups etc. For example, International Committee for the Conservation of the Industrial Heritage (TICCIH), International Council on Monuments and Sites (ICOMOS), Industrial heritage of Wallonia and Brussels association, Research Centre for Industrial Heritage CTU in Prague, International Visegrad Fund, Directorate for Cultural Heritage in Oslo, Association for Industrial Archaeology in Telford etc. [5—7].

Today research in the field of relevant problems of industrial heritage architecture in the Czech Republic is carried out by Prof. Ing. arch. T. Senberger, PhDr. B. Fragner, Prof. Ing. arch. P. Urlich, CSc., Doc. Ing. arch. P. Vorlik, Ph.D., Mgr. L. Beran and others (Czech Technical University in Prague), Prof. Ing. arch. H. Zemankova, CSc. (Brno University of Technology), Ing. arch. E. Dvorakova (National Heritage Institute in Prague) and others. Nowadays it is important to do research on this topic, to analyze the present problem and develop the conservation methods in terms of adaptive reuse of industrial heritage architecture that can solve all relevant problems: e. g. conservation of industrial heritage (industrial architecture objects, brownfields, historical industrial equipment and technologies), new effective use, integration of social, municipal, cultural and other components, improvement of microclimate in the area of industrial object etc.

NEW INSIGHTS INTO THE TYPOLOGY OF INDUSTRIAL ARCHITECTURE

The first processes of industrialization began in England in the late 18th century with introduction of the first manufacturing plants. Soon industrialization has followed France and Germany and then in the late 19th century whole Europe. Industrialization has made direct impetus for production on a large scale. Moreover, this has changed the world market [6—10].

It is reasonable to note that industrialization was important for the global development of architecture. Industrialization (i. e. industrial revolution) meant a qualitative leap for the industry, technology, transport, telecommunications, atomic engineering, development of radio and television, automation etc. [11—13]. In addition to the major social changes, industrialization like a process of change from manufactory and craftsmanship to factory production and development of industry have influenced the creation of new typological type of buildings — industrial architecture (production halls and multi-storey buildings) [14—16].

The industrial era introduced global changes that have occurred all European industry, which meant new goals and new means to achieve them. Moreover, industrialization has already taken place in various areas of industry: textile (weaving, wool, cotton etc.), sugar and flour-milling industry, brewing, distilling, starch industry, glass industry and the production of porcelain, paper, woodworking, iron and steel industry, construction, chemical and coal industry etc. Each industrial area for manufacturing was requiring new concepts and technologies [16].

The consequences of industrialization were also reflected in the typology of industrial architecture and their new features, such as [15, 16]:

- versatility and variability of buildings;

- unification and standardization of building components as well as whole buildings;
- indoor environmental quality;
- requirements for fire safety.

As the general requirement for the construction of industrial buildings was a distribution of mechanical energy though the building for machines — industrial architecture began to be used not only for workpeople, but also for a new era devices (*Fig. 1, 2*). Elimination of dependence on classical supporting construction (e. g. open layout of the floor plans, continuous windows on the facades is typical for the industrial architecture of the industrial era. [15, 16]. The new demands on the architectural design solutions meet mainly by supporting pillars in a more or less regular grid, supporting ceilings or roofs, simply called "skeletons" [16, p. 214].

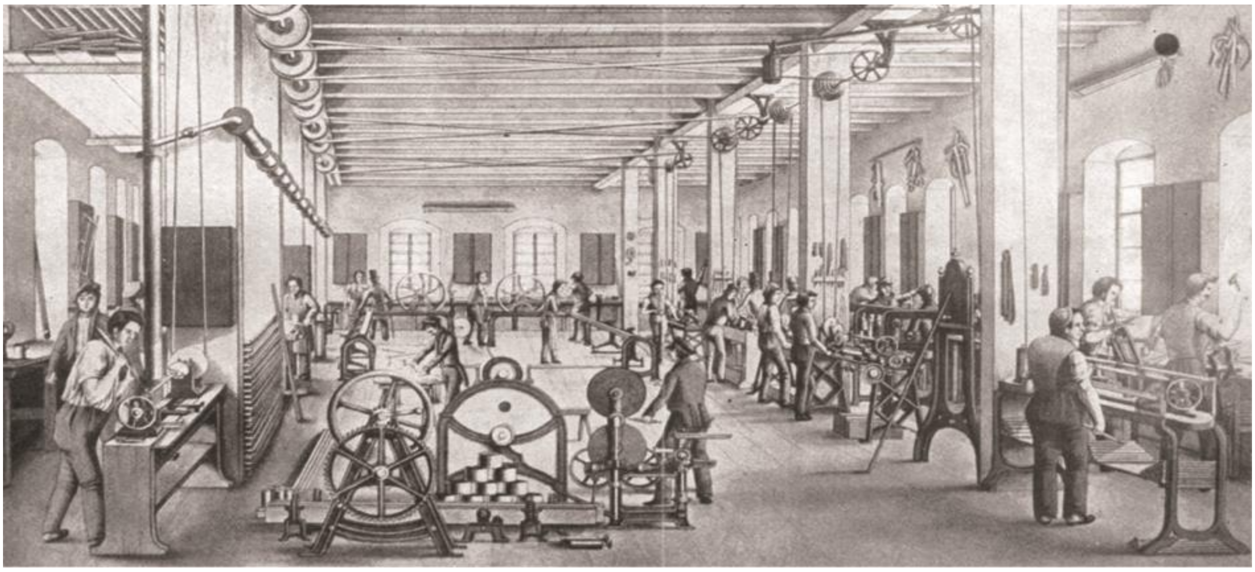
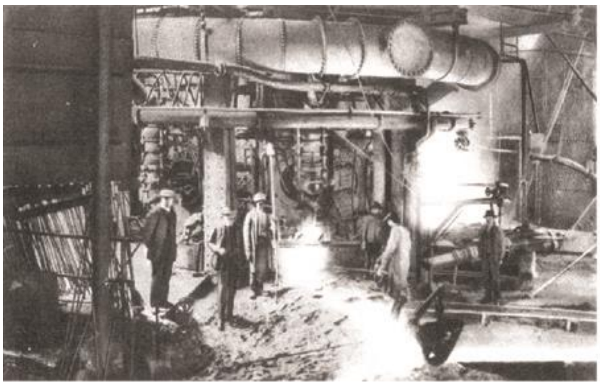


Fig. 1. Distribution of mechanical energy: manufacturing workshop of Bracegirdle machinery factory in Jablonec, 1840 [12]



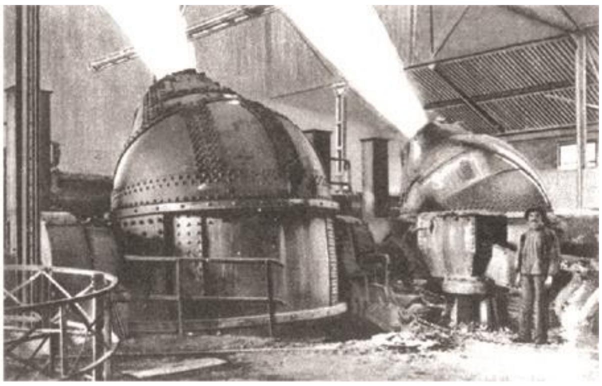


Fig. 2. Vítkovice Ironworks in 1913, Ostrava [17, p. 183] First buildings of a new era "had a massive stone or brick covering and wooden skeleton in the interior" (Fig. 3) [16, p. 214]. New solutions without wood in supporting construction came with the new innovative

materials and technologies— wood was replaced by iron construction (Fig. 4, 5) [15, 16, 18]. This design was suitable throughout the century. But soon typology of all industrial buildings was waiting for new changes. First of all, changes of the material of construction. The last decade of the 19th century was the period of reinforced concrete: a large number of multi-storey industrial buildings with monolithic reinforced concrete system of supporting constructions were built (Fig. 6) [18, 19].

Soon industrialization had the first results: e. g. decrease of production costs, development of new products and internal changes in society, including thinking and lifestyle of mankind. The maximum progress in the production during the period of industrialization was in the late 20th century (adoption of the aforementioned innovations, development of new materials and modernization of manufacturing processes) [11, 12].

Fig. 3. Wooden skeleton in Public Transport Museum located in the tram depot Prague-Střešovice (author's photo)

Fig. 4. Cast-iron columns in brewery building in Kralupy nad Vltavou (author's photo)

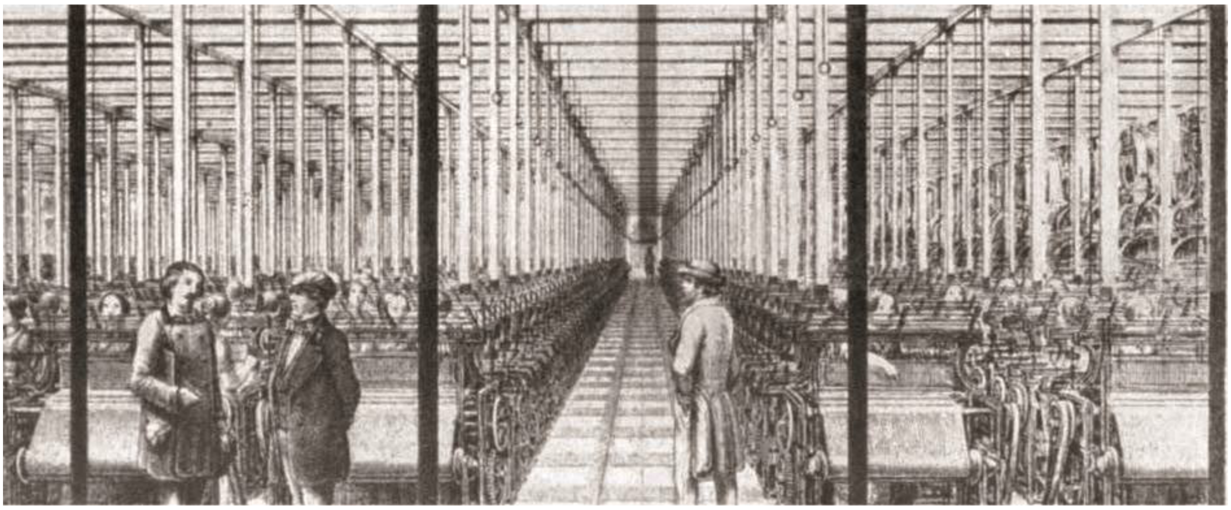


Fig. 5. Mechanical wool weaving mill Johanna Liebig & comp. in Liberec, late fifties of the 19th century [12]

Fig. 6. Interior of weaving mill Vonwiller in Žamberk, Ústí nad Orlicí [16, p. 217]

It is reasonable to emphasize, that the result at the beginning of the post-industrial period are changes in the typology of industrial architecture. In addition, the old industrial infrastructure gradually loses its functionality, e. g. [2, 5, 10, 15, 16 and 18]:

- industrial buildings as well as industrial areas become unsuitable for future use: effective use of industrial buildings for future manufacturing is not possible;
- implementation of new environmentally friendly technologies for future production is not possible;
- ineffective technologies of production;
- the possibility of a partial operation of the industrial building.

Modern industrial architecture today requires different architectural concepts and manufacturing technologies. Modern typology of industrial architecture has new standards that are not compatible with the architecture of industrial heritage, i. e. with the industrial architecture from the 18th — early 20th century.

As a result of further development, more technological and automated electronic devices were introduced into manufacturing; moreover, made from new materials. Buildings are becoming more compact. It was significant to note that the industrialization had a significant impact on technical and scientific progress, automation, new technologies, new trends in production and distribution etc.

GOALS AND TASKS OF CONSERVATION IN CONTEXT OF ADAPTIVE REUSE OF INDUSTRIAL HERITAGE ARCHITECTURE

Present research work deals with the problem of preservation and creating a new social functions for the architecture of industrial heritage that will be relevant to all sustainable and social problems. Under the present conditions of urban infrastructure in large industrial and urbanized cities in all European countries, it is reasonable to note, that the problem of industrial heritage preservation demands new experimental methods, which assume conservation and adaptive reuse of industrial heritage architecture for a new social functions taking into account all state preservation strategies [6].

It should be noted, that a new much more reliable strategy for conservation of the objects of industrial heritage - implementation of a comprehensive system for preservation of movable and immovable heritage, including historic industrial buildings - was realized with the 20th century [19].

Based on carried out analytical research work, the following goals and tasks of heritage conservation in context of adaptive reuse of industrial heritage architecture have been defined:

- historical (preservation of historical value of industrial buildings);
- architectural and artistic (preservation of architectural and artistic value of the concept of industrial building, preservation of internal organization and distribution of the original spaces including interiors);
- technical (preservation manufacturing equipment and technologies, movable monuments: e. g. machinery, transport and other equipment).

ADAPTIVE REUSE AS AN ACCEPTABLE APPROACH FOR CONSERVATION AND NEW USE

It is reasonable to emphasize, that the development of human society all over the world today has a direct impact on the environment and socio-cultural level of the population. Moreover, at the beginning of the post-industrial period, population began to pay close attention to various current problems of development technologies and approaches to safe and protect natural resources and the environment.

As a major precondition in context of present research work, it is important to take into consideration particular changes in all manufacturing trends (modern methods, technologies, concepts etc.), when companies in all developed countries changed from industrial to post-industrial phase. As a result, industrial buildings from the 18th — early 20th century are not suitable for production and it is not possible to modernize their infrastructure [2, 4 and 6].

A lot of interesting industrial heritage objects now are brownfields or are owned by commercial companies with an inactive or inefficient production with different types of pollution: pollution of the environment, atmosphere and groundwater, mutation of ecosystem, flora and fauna, including negative impact on the urban environment and landscape [2, 4]. Moreover, architecture of industrial heritage has a negative impact on a person's health, mental and emotional state, including the general demographic indicators and criminogenic situation in the city.

problem of protection and new effective use of the architecture of industrial heritage is relevant today and the importance of all these architectural objects as the "architectural monuments" in context of history of each country and city is very high.

Conservation and adaptive reuse of the architecture of industrial heritage have great importance and relevance for more than last fifty years. Tendency to protect industrial heritage has been dating since the sixties of the 20th century in Great Britain. Later, this problem has become more important in Western Europe (Germany, France, Belgium etc.). In Eastern Europe (the Czech Republic, Poland, Hungary, etc.) — after the fall of communism in 1989 [6, 16].

It is reasonable to note, that the deficit of "suitable social environment" is typical for large industrial and urbanized cities nowadays. It is necessary to create a new social, cultural and municipal objects based on industrial buildings and brownfields that will be used taking into account all environmental and social problems. This is the main reason why the adaptive reuse of industrial heritage architecture for a new social function was chosen as the most acceptable approach. Logical model of adaptive reuse of industrial heritage architecture as an acceptable approach for new use is shown in *Fig. 7.*

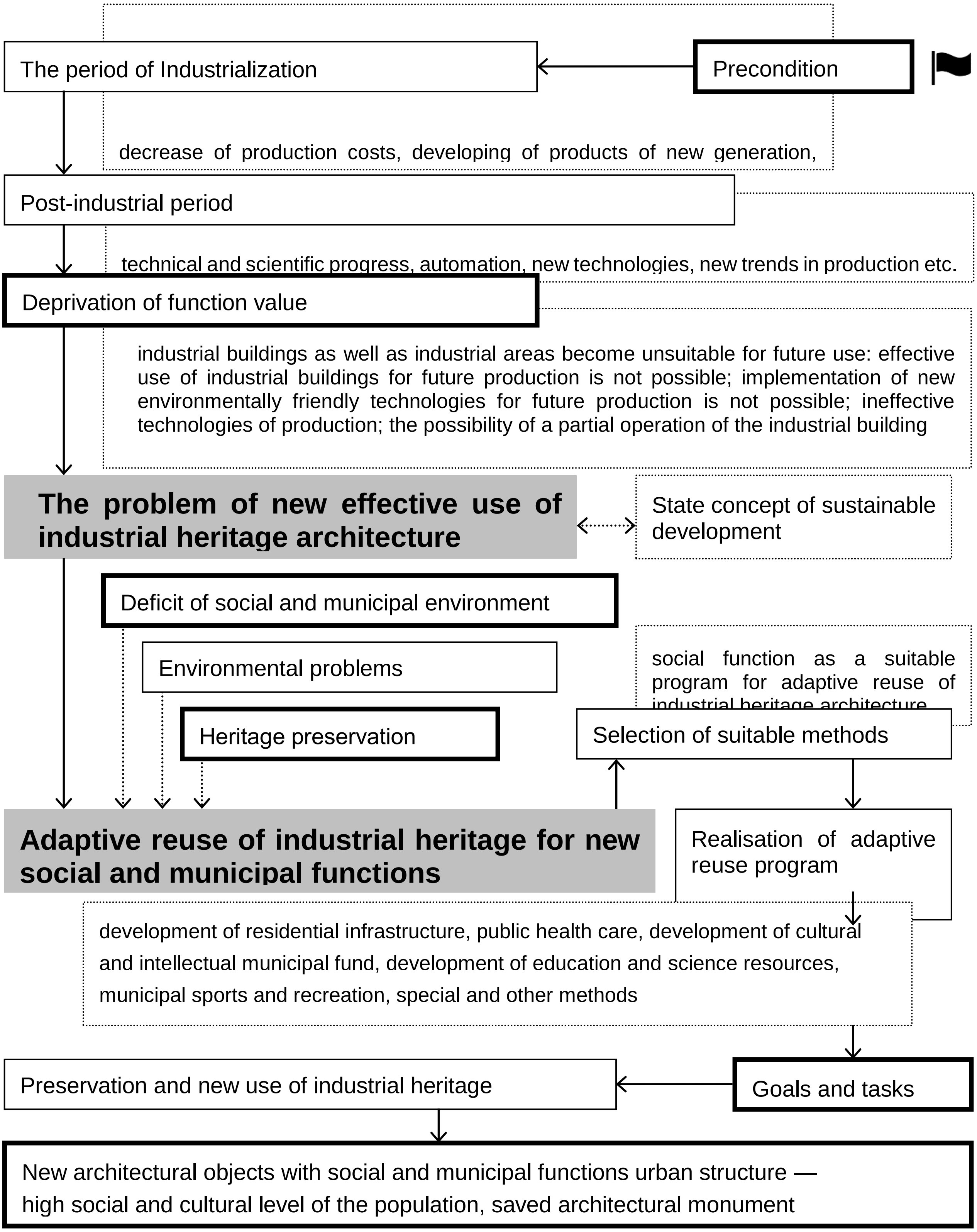


Fig. 7. Logical model of adaptive reuse of industrial heritage architecture as an acceptable approach for new use

METHODS FOR THE CONSERVATION OF INDUSTRIAL HERITAGE ARCHITECTURE BY THE ADAPTIVE REUSE APPROACH

Based on carried out analytical research work the following general methods for industrial heritage preservation have been defined:

- historical method;
- architectural and artistic method;
- technical method.

These methods can be respected all as well as a single or their different combination that depends on each specific building. The basis for future adaptive reuse of industrial heritage taking into account goals and tasks of heritage preservation is a new "sustainable program" — a new function.

There are six most important and relevant functions for adaptive reuse: residential, public health, cultural, education and science, sports and recreation, special and other. According to defined functions, it is reasonable to classify following functional methods' concepts (social concepts):

- development of residential infrastructure (e. g. hostels, student hostels, social accommodation, house for aged, hotels, pensions etc.);
- public health care (hospitals, health centers and service, social institutions etc.);
- development of cultural and intellectual municipal fund (museums, libraries, concert halls, exhibition centers, galleries, workshops, theaters etc.);
- development of education and science resources (e. g. kindergartens, schools, colleges, universities, schools of art, study and reading rooms, dance halls, laboratories, research centers etc.);
- municipal sports and recreation (sports clubs, swimming pools, fitness centers, parks, botanical gardens etc.);
- special and other methods.

It is reasonable to emphasize, that the characteristics of each method are conditioned but another additional factors. Optimal new function is especially function with social or municipal importance for population.

Another important factor influencing new function is a character of financing. Most industrial heritage objects protected by adaptive reuse approach are initiated by commercial interests. In some cases, financed by European Union, government, grand etc.

Some methods for industrial heritage preservation in the frame of adaptive reuse for new social and municipal have been respected nowadays in the Czech Republic: there are lots of adaptive reuse projects successfully realized during the last ten years. For example, National Cultural Monument " Dolní oblast Vítkovice" in Ostrava (former mine, coking plant, blast furnaces and the other technological facilities of metallurgical basic industry and energetics metallurgical plant), adaptive reuse of the former brewery into the Administrative Center of Hradec Králové Region with the Regional Council of the Hradec Králové region, Department of Arts of the Hradec Králové University etc. (*fig. 8 and 9*).

BENEFICIAL EFFECT OF THE ADAPTIVE REUSE APPROACH

It is important to emphasize the beneficial effect on different levels in context of adaptive reuse of industrial architecture for new social and municipal functions as the conservation concept for new effective use in the Czech Republic as well as other developed countries: first of all, the development of social and municipal area and renovation of the environment [1, 2, 5].

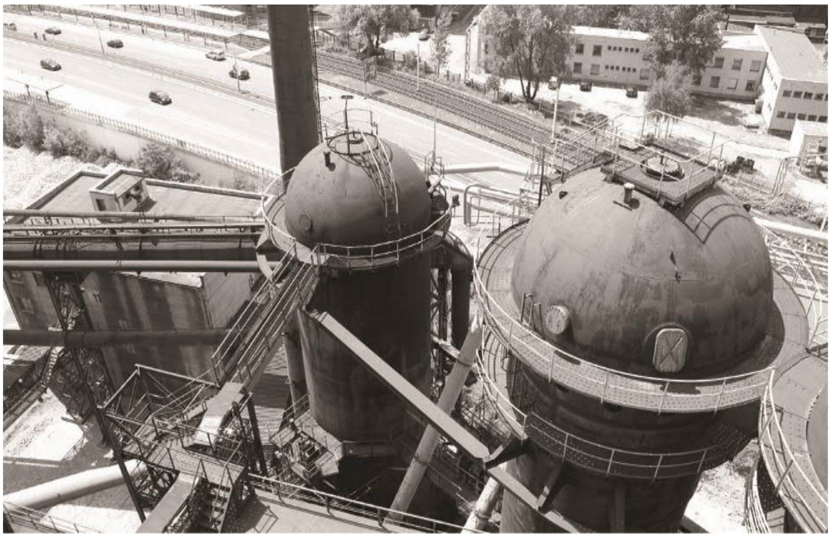


Fig. 8. National Cultural Monument "Dolní oblast Vítkovice" in Ostrava (author's photo)

Fig. 9. Administrative Center of Hradec Králové Region (author's photo)

The beneficial effect of adaptive reuse approach is focused on a person, conservation of industrial heritage object by the development of stability in social and cultural systems. Adaptive reuse approach is directed to solve following important problems:

1. General social and municipal problems:
   - deficiency in residential infrastructure;
   - deficiency in public health care institutions;
   - deficiency in cultural institutions and intellectual municipal fund;
   - deficiency in new education institutions and science resources;
   - deficiency in sports and recreation infrastructure;
   - deficiency in other (special) social and municipal areas.
2. Companion problems:
   - negative influence on the environment;
   - negative influence on health, psychic and emotional state of people;
   - negative influence on demographic indices;
   - negative influence on visual environment;
   - negative influence on criminogenic situation.

Moreover, adaptive reuse approach with conservation of industrial heritage architecture has beneficial effect on renovation and protection of the environment.

CONCLUSIONS

1. The relevance and topicality of the problem of adaptive reuse of industrial architecture for new social and municipal functions as the conservation concept has been defined.

2. New insights into the typology of industrial architecture have been reviewed: global changes in all European industry, new concepts and technologies in manufacturing, new features of industrial architecture and their construction and typology, first results of industrialization and changes in the typology of industrial architecture in post-industrial period.
3. General goals and tasks of conservation in context of adaptive reuse of industrial heritage architecture have been defined: historical, architectural and artistic, technical.
4. Adaptive reuse as an acceptable approach for conservation and new use has been proposed and reviewed. Logical model of adaptive reuse of industrial heritage architecture as an acceptable approach for new use has been developed.
5. Methods for the conservation of industrial heritage architecture by the adaptive reuse approach have been developed: historical, architectural and artistic, technical. Moreover, relevant functional methods' concepts (social concepts) have been defined and classified.
6. General beneficial effect of the adaptive reuse approach has been defined.

ACKNOWLEDGEMENTS

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Article no. 2

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DRAFT MODEL FOR CREATING A FINANCIAL INDICATORS OF BRIDGE CONSTRUCTION

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ABSTRACT

The paper deals with a problem of developing, defining and applying budgetary indicators of engineering constructions, and particularly bridges. It is a draft of a Model for development of budgetary indicators of bridge construction in the pre-investment phase of a project. It could, according to classification and evaluation in terms of criteria and search for the most accurate valuation unit of complex structures such as bridge construction, serve investors and public administration authorities for rapid investment planning and professional control of completed buildings. Such a unique tool has never been developed in the Czech Republic so far.

Bridges as buildings complement any landscape and in the outer parts of cities, they often establish a viewpoint. They belong among important parts of any highway or expressway. Without them, it would be impossible to establish grade-separated crossings with other roads - roads, railway lines or sections of rivers. They are also important in overcoming obstacles of natural and artificial character such as deep valleys, lakes, or steep mountainsides.

The aim of the paper is to analyse a current state of the valuation of bridges and the subsequent establishment and validation of the Model for the development of budgetary indicators of the bridge construction.

KEYWORDS

Bridges, basic budgetary costs, budgetary indicators, preliminary cost overview, budget, concrete, founding, rocks, abutments, wings, pillars, bridge deck, field

INTRODUCTION

“Bridge – an engineering work or a statue?”

Recently, we have been seeing increasingly more signs that construction of Czech highways and roads, and the related construction of highway and road bridges, is more costly both when compared with economically equivalent Central European states and with economically more advanced Western European states. This concerns both construction of new bridges and unsatisfactory condition of already built road and highway bridges. The most widespread opinion is that the current condition of most bridges is unsatisfactory and that it is caused by many factors including above all:

- age of the constructions (see D1 highway bridges),
- significantly increased and more dynamic load as compared with original assumptions,

- bad quality of earlier used insulation and other materials,
- insufficient maintenance and not ensuring timely repairs of small defects,
- atmospheric and chemical effects,
- failures caused by unexpected events (accidents etc.).

RESEARCH GOAL

The research was conducted at the Faculty of Civil Engineering - Department of Economics and Management in Civil Engineering within the preparation of the dissertation. The goal of the research is to analyse a current situation in pricing and, on the resulting basis, to propose a model for creation of budget indicators of bridge structures.

A significant part of the system of pricing of buildings and constructions is evaluation of construction projects in the phase of planning and calculation of construction costs. Budget indicators, or also the prices according to purpose measuring units, are the basic elements for the first calculation of price of buildings and constructions in the phase of pre-project preparation of a construction project. This calculation is a professional estimate of the future price of the construction, which serves as first-level information for investors related to the future price of the construction work. It is necessary to have especially a construction study proposal documentation for planning permission proceedings at your disposal.

Overview of used research methods:

- Analysis and synthesis
- Correlation and regression analysis
- Descriptive statistics – statistic classification of data – histogram of frequencies.

Two basic research questions arise in connection with the above-mentioned opinion:

- Why do study results often state a high price for construction of a bridge structure?
- Do budget indicators from the companies ÚRS PRAHA, a.s. and RTS, a.s. reflect the actual reality?

Summary of the literature connected with the subject of paper:

- Spon´s Civil Engineering and Highway Works Price Book [1]
- Stráský, J. (2001). *Betonové mosty* [2]
- Bridge Engineering: Construction and Maintenance [3]

Current situation of the issue in the Czech Republic

Main used budget indicators of a construction structure (RUSO)

The basic elements necessary for the first calculation of price of constructions in the pre-investment phase of a construction project are budget indicators. These budget indicators are created by special private organisations in CZR, such as:

- ÚRS PRAHA, a.s., [4]
- RTS Brno, a.s., [5]
- Ředitelství silnic a dálnic ČR (publicly inaccessible on the basis of realised constructions),
- IBR Consulting s.r.o. (publicly accessible updated prices for pricing of construction in the phase of DÚR).

Professional literature covering the topic of bridges is mostly technically oriented in the Czech Republic. This refers to the book called "Betonové mosty I / Concrete Bridges I" taking into consideration the relation between technical design and price [6]. From among the international sources, particularly German professional literature reports on this topic. [7]

Currently, as of 2013 – 2014, approximately 17 445 bridges are recorded in the Czech Republic, of which 1 568 are on highways and skyways, 3 286 bridges on I-class roads, 4 516 bridges on II-class roads and 8 075 bridges on III-class roads [8].

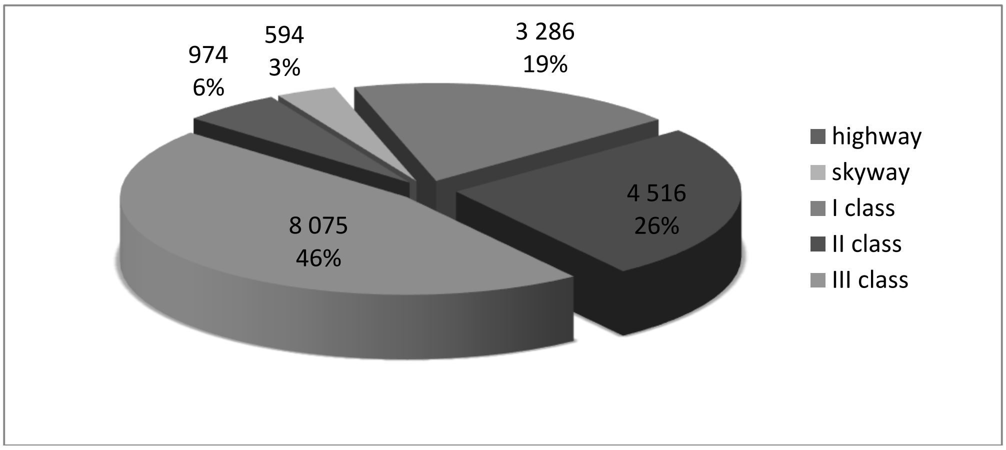

Fig. 1: Classification of bridges according to the type of the road, Source: own elaboration

The following graph shows an overview of bridges on highways and I, II and III-class roads according to the type of the load-bearing structure. The most frequent bridges from the perspective of characteristics of the used material are bridges with concrete load-bearing structure.

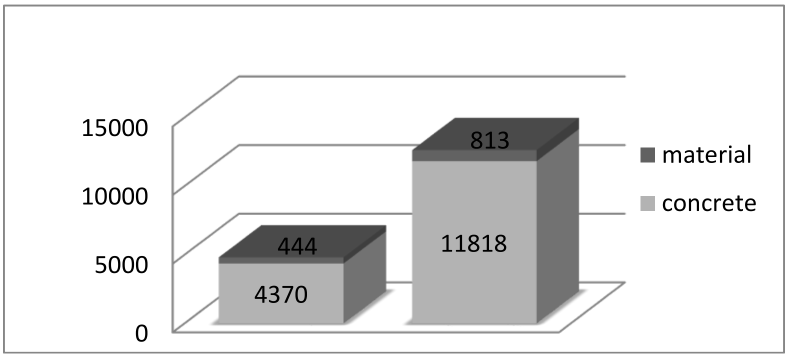

Fig. 2: Overview of bridges according to the type of the load-bearing structure, Source: own elaboration

Predominance of bridges with concrete load-bearing structure is one of the main reasons for focus of this work.

According to the Czech construction standards, acceptable differences between the calculated and real costs are within the range of $^{+}_{-}$ 15%. [9]

Characteristics of the subject of the solution

Solution procedure

To find a correct solution for the given issue, it is necessary to know bridges from the technical and price point of view.

Item budgets were elaborated by means of the software ASPE on the price level 2013 (basic budget costs without VAT and without costs on placement of the construction) on the basis of project documentation and bill of quantities. It is a software “Automatizovany System Podnikove Ekonomiky” (Automated Corporate Economy System), which is designed for preparation and realisation of constructions and which is used especially for realisation of roads and it is also very important for elaboration of bridge cost calculations.

Random effects related to general constructions and works were removed from item budgets. The price does not include:

- Elaboration of a bridge sheet,
- testing of material by an independent testing centre,
- testing of constructions and works by a testing centre of the contractor – preliminary agreement,
- testing of constructions and works by a testing centre of the contractor,
- other requirements – land survey measurements,
- geodetic surveying,
- assessments, inspections, revision reports,
- main bridge inspection,
- documentation of actual realisation in a digital form.
- disposal site fee

In general, it applies that each bridge is an original with regard to its position, technology and other effects. Therefore, items related to general constructions and works are not used in the proposal of creation of budget indicator. The analysis shows that in the case of bridge constructions, general constructions and works form 4 – 5% of the total basic budget costs. **The disposal site fee is considered only at the general level in the proposed model.**

For a better transparency, a table was elaborated for 13 samples of designed bridges with the load-bearing structure “prefabricated prefa girder”. The table shows deviations from the real basic budget costs as compared with costs determined according to the indicator price ÚRS Praha, a.s. and RTS Brno, a.s. on the price level 2013. It includes basic budget costs without VAT and it does not include costs of placement of the construction.

Tab. 1: Bridges PREFA GIRDER, Source: own elaboration

Bridge name	Basic budget costs (BBC) compared with costs according to the indicator price of URS PRAHA, a.s. (%)	Basic budget costs (BBC) compared with costs according to the indicator price of RTS Brno, a.s. (%)
Bridge D1 203	87,14	95,46
Bridge D1 046 km 44,294	162,40	174,06
Bridge D1 045 km 43,444	167,01	178,88
Bridge D1 194	98,26	107,07
Bridge D1 200 km 161,976	76,92	84,78
Bridge Litoměřice - Mlékojedy	45,08	51,53
Bridge D1 069km	32,82	38,72
Bridge D1 071 behind the municipality Studený	16,56	21,75
Bridge D1 066km u Lokte	28,81	34,53
Bridge D1 140	5,12	9,80
Bridge D1 050 km 47,864	-16,61	-12,90
Bridge D1 044 km 42,661	-27,12	-23,88
Bridge D1 139 km 106,27	-35,47	-32,60

On the basis of costs mentioned in *Tab. 1* we could say even surprising deviations, which show us the percentage manifestation of the real costs compared with costs according to the indicator price established by the companies ÚRS Praha a.s. and RTS Brno on the price level 2013, it will be necessary to find new budget indicators, to classify the bridges and their material characteristics more precisely and to define the basic evaluation unit.

Methodology for creation of price indicators of bridge Structures

Proposal of a new classification for concrete bridges, which is based on general classification of bridges:

- According to the type of transport:
    - road bridges.
- According to the type of obstacle (from the perspective of the bridge project):
    - highway and skyway overpasses,
    - highway and road bridges,
    - embanked bridges,
    - single-span bridges,
    - urban viaducts,
    - bridges across rivers,
    - bridges across deep valleys,
    - pedestrian bridges.

- According to technologies:
  - prefabricated structure,
  - monolithic structure,
- According to the load-bearing structure:
  - board structure,
  - beam construction (beam + box girder),
  - arched bridges,
  - suspension and hanging bridges.
- Frame culverts and embanked structures. [10]

Tab. 2: Proposal of a new classification of bridge structures, Source: own elaboration

821 BRIDGES			**Number of bridges**	**Classification according to the bridge material characteristics**					
821 1 Road bridges				**1**		**2**		**3**	
821 11 CONCRETE BRIDGES	1	Highway and skyway overpasses	16				9		7
	2	Highway bridges	17		7		2		8
	3	Road bridges	13		8		5		

Construction material characteristics:

- 1 monolithic concrete prestressed board structure
- 2 monolithic concrete prestressed beam structure
- 3 assembled from parts of prestressed PREFA GIRDER [11]

Selection of relevant criteria, defining their variants and creation of the basic representative – price indicator of the given bridge structure.

The proposed methodology has been applied on the database of 46 concrete bridges, which are classified into 7 groups according to construction material characteristics

Example:

Road bridges, concrete bridges, highway and skyway overpasses, load-bearing structure assembled from parts of prestressed PREFA GIRDER.

821 11 13

Tab. 3: Bridges - PREFA GIRDER, Source: own elaboration

Bridge name	Bridge parameters (m, m, m, m, m^2)					BBC without VAT and CPC in PL 2013	BBC/areas and L-BS
	Length L-BS	Span	Aver. span	Bridge width	L-BS area		
Bridge D1 066km u Lokte	45,7	21,7+22,3	22	6,6	331,55	11 977 171 CZK	36 125 CZK
Bridge D1 069km	47,7	22+24	23	7,7	367,29	12 867 848 CZK	35 035 CZK
Bridge D1 071 behind the municipality Studený	37,7	36	36	10,5	395,85	15 802 087 CZK	39 919 CZK
Bridge D1 140	48,47	24,35+24,12	24,24	7,8	378,066	16 734 667 CZK	44 264 CZK
Bridge D1 194	51,34	24,8+24,8	24,8	7,7	375,84	8 821 071 CZK	23 470 CZK
Bridge D1 200 across highway on a field path 161,976 km	49,8	24,5+24,5	24,5	7,7	375,84	9 885 140 CZK	26 301 CZK

The anticipated dependency between the variables was discovered **by means of the correlation and regression analysis:**

- BBC and amount of the dug-up earth, backfill and embankment (m^3)
- BBC and amount of concrete including bridge supports, wings, cornice (m^3)

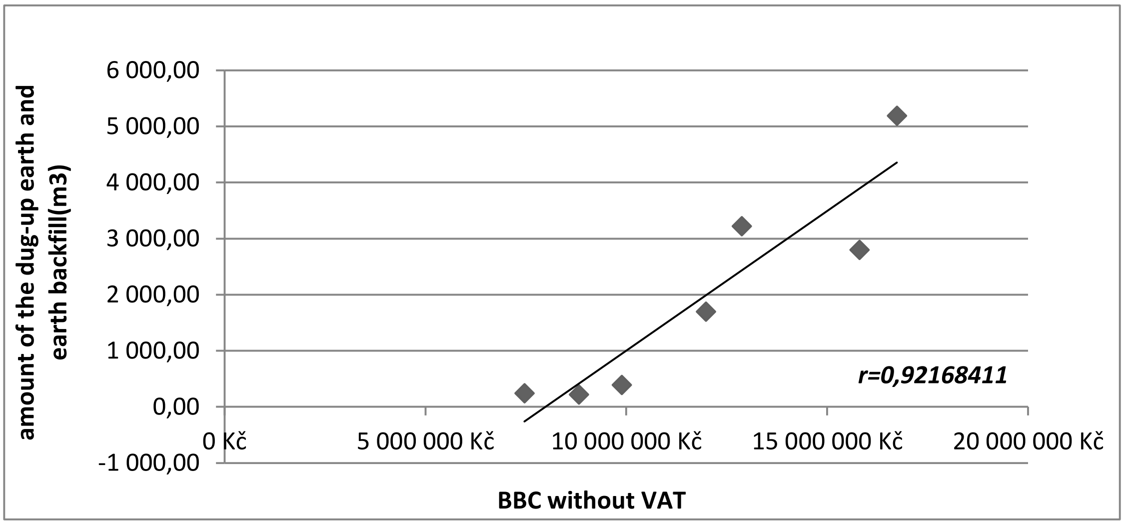

Fig. 3 BBC/amount of the dug-up earth and earth backfill (m^3), Source: own elaboration

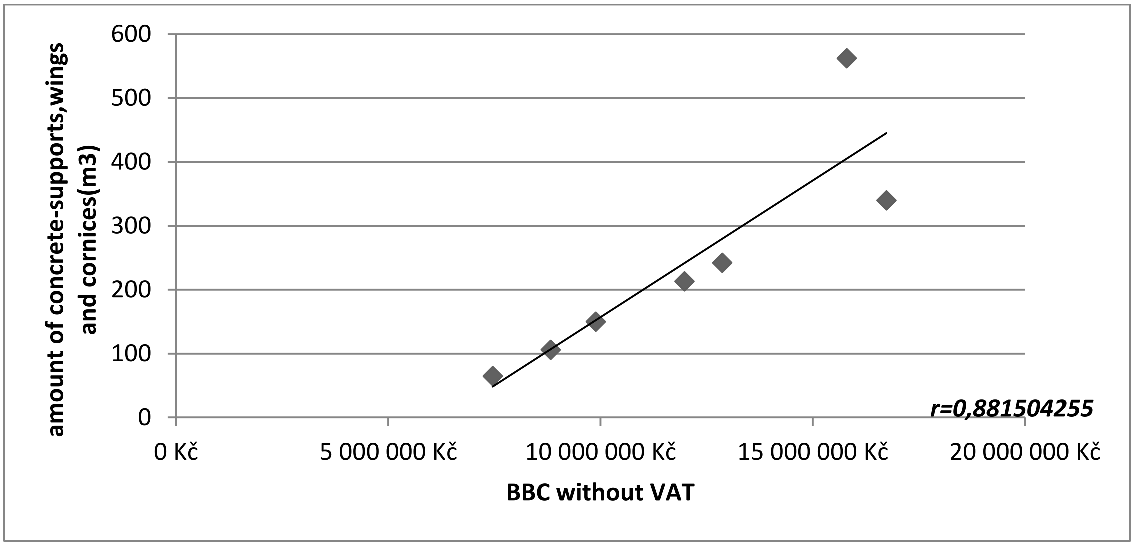

Fig. 4: BBC/amount of concrete-supports,wings and cornices (m^3), Source: own elaboration

Last step of the proposed methodology is creation of the basic representative – price indicator of the particular bridge structure with the given material characteristics.

- To define variants on the basis of comparative statistics methods, where the occurrence frequency of variants for the proposed relevant criterion was determined.
- Variants with the most frequent occurrence for each relevant criterion were selected and, on the basis of the method mentioned in the previous step, 3 representatives were defined, which have similar values in their selected criteria.

The representative – price indicator was selected with basic parameters and resulting averaged guide price for 1m^2 of the area of the load-bearing structure **37 026CZK/m^2**. Values, which are stated in the proposed relevant criteria, were determined by means of arithmetic means with the number in the absolute value.

Selected representative

Indicative price/m^2	CZK3**7.** 026per square
Amount of digging works	1 001 – 5 000m^3
Foundation difficulty	1 – surface area
Class of rocks	II – III
Amount of concrete in m^3	
(Bridge supports, wings and cornices, ŽL class, B37)	201 – 500m^3
Bridge floor area	301 – 400m^2
Number of fields	2

As bridges are also designed in different values than the selected representative, it was necessary to optimise the price of the real or particular bridge with regard to its designed parameters, especially in the following variants, which include the individual relevant criteria.

- Class of rocks higher than III
- Amount of digging works to 100m^3,101-1000m^3, over 5000m^3
- Foundation difficulty special foundation -2 (boreholes, piles, sheet-pile walls)
- Number of fields 1, 3 and more
- Area of bridge floor to 300m^2, 401-600m^2, 601-900m^2**,** over 901m^2

The newly proposed indicators of an average guide price (budget price) were related to the measuring unit m^2 in the following table on the basis of the above-mentioned methodology for creation of a representative of a bridge structure.

Tab. 4 Guide price indicators related to m^2, Source: own elaboration

<table>
<tr><th colspan="3">821 BRIDGES</th><th rowspan="2">Number of bridges</th><th colspan="6">Classification according to the bridge construction material characteristics</th></tr>
<tr><th colspan="3">821 1 Road bridges</th><th colspan="2">1</th><th colspan="2">2</th><th colspan="2">3</th></tr>
<tr><td rowspan="3">821 11 CONCRETE BRIDGES</td><td>1</td><td>Highway and skyway overpasses</td><td>16</td><td></td><td></td><td>37 300 CZK</td><td>9</td><td>37 000 CZK</td><td>7</td></tr>
<tr><td>2</td><td>Highway bridges</td><td>17</td><td>35 600CZK</td><td>7</td><td>31 300 CZK</td><td>2</td><td>30 200 CZK</td><td>8</td></tr>
<tr><td>3</td><td>Road bridges</td><td>13</td><td>33 600CZK</td><td>8</td><td>32 900 CZK</td><td>5</td><td></td><td></td></tr>
</table>

Results from the suggested methodology for “Road bridges – Concrete bridges” are the basis for a model for creation of budget indicators of a bridge structure.

CONCLUSION

The resulting model will enable simple specifying of investment costs for construction of new concrete bridges as civil structures (i.e. highway and road bridges, including highway and motorway flyovers). It may be used in the pre-investment phase allowing fast and specifically exact pricing of planned investment. Investors and/or designers may use it as well as other professionals.

There are 17.445 bridges of different age in the Czech Republic. Determining construction costs of their repair, maintenance, or modernisation will be topic of the day in the upcoming years (due to the life expectancy of for instance bridge floor insulation, as it is around 20 years). This is why the Model will be designed allowing adding more modules.

- Module OC – steel-concrete bridges.
- Module PK – backfilled structures – bio-corridors.
- Module OU – repair and maintenance of bridges.
- Module RE - modernisation of a bridge.
- Module RM – construction of railway bridges, industrial, water-management corridors, and pedestrian bridges.

It must be considered that investment costs defined by the model do not contain related costs unsubstantiated in the database of directional costs, and these are first of all:

- cost of project documents,
- cost of geodetic survey,
- testing of structures and work by contractor's test lab – preliminary,
- testing of structures and work by contractor's test lab,
- other requirements – geodetic surveying, expert opinions, check-ups, revision reports,
- key bridge inspection,
- digital as-built documents,
- VRN (NUS) / additional budgeted cost (site-related costs),
- VAT.

On the other hand, the market environment (contractors' interest to build) sometimes pushes investor costs down by as much as 20-30 per cent compared to directional costs specified in the Model. Yet the Model is structured in such a manner so that the basic entry data could be updated and still maintain costs relative to affecting parameters.

ABBREVIATIONS

ÚRS PRAHA, a.s. - the successor to the oldest organisation of this type in the Czech Republic that was the state-owned Ústav pro racionalizaci ve stavebnictví / Institute for Rationalization in Construction Engineering liquidated at the beginning of the 1990s.

821 11 13 - Concrete bridges Highway and skyway overpasses assembled from parts of prestressed PREFA GIRDER .

BBC - basic budget costs

CPC - costs on placement of the construction

PL 2013 - price level 2013

L-BS - load-bearing structure

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COMPARISON OF TUNNELLING METHODS NATM AND ADECO-RS

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ABSTRACT

The New Austrian Tunnelling Method (NATM) has been often used in the Czech Republic in last two decades. One of the methods, without application in the Czech Republic, is an Italian method called ADECO-RS, which has reached significant use in Italy and some other countries. It is the method of controlled deformation, which uses mainly the horizontal anchoring of the tunnel face to reinforce the area in front of the face (advance core). This technology is especially important in weak and soft rocks where is necessary to excavate quickly and smoothly with minimum disruption of initial stress state of the rock mass in the vicinity of the excavation. The use of NATM can be in some cases uneconomical and technically inadequately challenging and in such cases would be appropriate to choose another technology.

Given the facts above, in the Czech environment there is no data available for comparison of these methods not only in terms of numerical modelling, but also in terms of feasibility and usability.

The paper summarizes history of the tunnelling methods and it is closer devoted to NATM and ADECO-RS tunnelling approaches. The basic principles of both methods are set and further the comparison of these methods is made on a theoretical level.

The paper hereinafter includes the analysis of fibreglass face anchors application during the construction of three-aisled Veleslavín Station and the impact assessment of tunnel face anchoring during the excavation of ventilation tunnel on the newly built part of the Prague Metro „V.A“.

The paper also deals with practical knowledge gained during the technical visit of Italian Val di Sambro Tunnel which is built according to ADECO-RS approach. These findings are essential for the correct interpretation of Lunardi method.

KEYWORDS

NATM, ADECO-RS, tunnelling methods, advance core, deformation response of the rock mass

INTRODUCTION

The necessity for tunnels and the benefits they bring cannot be overestimated. Tunnels improve connections and shorten lifelines. Moving traffic underground, they improve the quality of life above ground and may have enormous economic impact. Of course, the construction of tunnels is risky and expensive and requires a high level of technical skill. [1]

Despite great development and expansion of tunnelling in the world, a price of some tunnels in the Czech Republic is higher than in Western EU countries. For the last 20 years New Austrian Tunnelling Method was a prevailing tunnelling method in the Czech Republic (leaving aside the TBM technology, which is becoming increasingly used in recent years), thus it could be one of the reasons for high prices. The method which has not been used in the Czech Republic yet but with which a number of tunnels was built in adverse conditions, is the method called ADECO-RS (L'Analisi delle Deformazioni Controllate nelle Rocce e nei Suoli). This method was developed in eighties in Italy by Professor Lunardi.

The methods mentioned above differ in philosophical views on the behaviour of ground mass during excavation and the method of stabilization of the excavated opening. The result is a completely different approach towards the tunnelling technique and calculation of primary and secondary lining. So far just a small effort was generated to promote ADECO-RS method in the Czech Republic. [7]

NATM

NATM was originally developed for use in the Alps, where tunnels are commonly excavated at depth and in high in-situ stresses conditions. The principles of NATM are fundamental to modern day tunnelling, however most city tunnels are built at shallow depth and without the need to control the release of the in-situ stress and instead want to minimise settlement. [2]

NATM broadly based on the following principles:

- Mobilization of the strength of rock mass.
- Shotcrete protection and flexible support.
- Measurements - every deformation of the excavation must be measured.
- Closing of invert - quickly closing the invert and creating a load-bearing ring is important.
- Rock mass classification determines support measures - there are several main rock classes for tunnels and corresponding support systems for each.
- Dynamic design – the designing is dynamic during the tunnel construction. Every face opening classification of rock is done and the supports are selected accordingly.
- The tunnel is sequentially excavated and supported, and the excavation sequences can be varied.

ADECO-RS

This method was developed in eighties in Italy by Professor Lunardi. As the name ADECO-RS (L'Analisi delle Deformazioni Controllate nelle Rocce e nei Suoli) says, it is a method of controlled deformation. Its introduction to tunnelling practice can be dated as occurring in 1985

when it was tried out for the first time in the world by the Professor Lunardi and Doctor Bindi during the construction of some tunnels on the Florence-Arezzo section of the new high speed railway line between Rome and Florence. [4]

ADECO-RS broadly based on the following principles:

- The deformation response of the medium to the action of excavation must be principal question with which a tunnel designer is concerned, because, amongst other things, it is an indicator of the triggering and position of an arch effect or in other words the level of stability reached by the tunnel. [5]
- The deformation response begins ahead of the face in the advance core and develops backwards from it along the cavity and that it is not only convergence, but consists of extrusion, preconvergence and convergence. Convergence is only the last stage of very complex stress-strain process. [4]

Fig. 1. Drilling of the tunnel face anchors, Val di Sambro Tunnel, Italy (author's archive)

- There is the existence of a direct connection between the deformation response of the face - advance core system and that of the cavity in the sense that the latter is a direct consequence of the former underlining the importance of monitoring the deformation response of the face-advance core system and not just the cavity.
- It is possible to control deformation of the advance core and as a consequence also control deformation of the cavity by acting on the rigidity of the core employing measures to protect and reinforce it.
- The application of ADECO-RS concept requires the use of equally rigid linings as an absolutely essential condition.
- It is important that maximum care and attention must be paid to ensure that the continuity of action in the passage from preconfinement to confinement occurs as gradually and as uniformly as possible. [6]

Theoretical Comparison of NATM and ADECO-RS

Conventional tunnelling methods, among which the two above-mentioned methods belong, are able to more or less respond to actually encountered geotechnical conditions and operatively change the means and method for stabilising the excavation. Changes in the state of stress are associated with deformations of the excavated ground surface or the primary lining, as well as the whole area in the vicinity of the excavation. In a built-up area or in the cases where a tunnel passes under structures or facilities sensitive to subsidence, the choice of the technological construction procedure is affected by a requirement for limitation of deformations of the overburden. Experience from practice and results of 3D mathematical modelling have proved that a part of ground mass deformation takes place ahead of the tunnel face. Another part occurs before the primary lining is installed and an anchoring system or other measures are implemented. The latter part of deformation takes place freely and is not controlled by accompanying measures. The remaining part of deformation produces loads on both primary and secondary tunnel linings, thus it can be controlled by accompanying measures. The proportion of the free deformation to the controlled deformation varies, depending on geotechnical properties of ground mass, the height of overburden, the excavation dimension and the construction method.

The practice has proven even a negative effect of dividing the tunnel face into a higher number of partial headings. The ground mass near to the excavated opening degrades and its geotechnical properties worsen. Each subsequent partial excavation therefore passes through a worse environment than the preceding one was.

Dimensions of the primary lining are optimised and the technical solution is economically favourable if the optimum moment for the installation of the primary lining or implementation of accompanying measures stabilising the excavation is found. Limiting values of the tunnel settlement overburden are set because of a damage risk to buildings in the zone affected by excavation. This principle is applicable only in cases where limiting values of the tunnel settlement overburden do not have to be maintained.

The time factor of the excavation support must be assessed from two aspects, from the aspect of its influence on the stability of the face and from the aspect of its influence on the loads acting on the lining. The growing time gap between the excavation and activation of the lining may cause a growth in stability problems both transversally and longitudinally. On the other hand, regarding the loads acting on the lining, an optimal time gap in the activation of the lining may reduce the load on the lining imposed by the rock mass. These two contradicting requirements must be harmonised and an acceptable compromise must be found. A condition for effective exploitation of the composite action of the rock mass-lining system for achieving minimum loading while maintaining stability of the tunnel and keeping the rock mass deformations within allowable limits (both transversal and longitudinal) is, among others, that deformational manifestations of the rock mass are objectively determined not only behind the tunnel face but also ahead of the face, with the aim of determining the part of the overall deformation which is no more transferred to the lining. Stress-strain manifestations of the rock mass are affected above all by stabilisation measures implemented at the face and its reinforcement. [7]

Veleslavín Station

The tunnel face fiberglass anchoring was used only in terms of increasing its stability without taking into account the influence on increasing the stiffness of advance core. In such unfavourable geological conditions, it is difficult to achieve constant progress of excavation and associated continuous deformation response of the rock mass. From the measured values of convergence a gradual process of settlement without significant skips was apparent. This behaviour can be partially attributed just to the systematic use of horizontal face anchors, which - for greater effect in reached conditions - had to be located into the face in a denser regular grid.

Unfortunately neither preconvergence ahead the tunnel face nor the extensometric measurements of the tunnel face extrusion were monitored, of which the effect of fibreglass face anchoring would be evident and it could be derive the number of anchors per m^2 of the face necessary to achieve the desired behaviour of the rock massive in conditions reached by excavation.

Fig. 2. Face anchors installation, Veleslavín Station, Czech Republic (author's archive)

Ventilation Tunnel within the Prague Metro Extension – Construction Object „02-29/01"

Although the realization of the access tunnel itself preceded the remediation of the excavation environment - which was a combination of sealing vertical walls made of double jet grouting columns carried out from the surface and the containment over the tunnel top-heading from sub-horizontal jet grouting columns reinforced with micro piles – it is an underground construction in the Czech tunnelling industry that reasonably resembles ADECO-RS.

Unfortunately contractor did not use the ADECO-RS approach in encountered and very complicated conditions due to fear to accept a non-traditional solution.

Construction phases according to ADECO-RS approach in the Val di Sambro Tunnel

The first activity is **ground improvement of the core-face** which starts with drilling and continues with insertion of 100 fibreglass elements at the face (L=24, 00 m, overlapping = 12, 00 m). The fibreglass anchors are implemented to the core-face variably, anticipated in the design as a function of the deformation response observed during construction (extrusion-convergence) can be up to 140, of which 40 operated so as to constitute a zone of improved ground around the advance core. The next step is cement grouting of the fibreglass elements.

Note: Drainages surrounding the core-face if necessary.

The second workflow consists of **excavation and primary lining installation.** The first advance cycle is carried out, planned length: 6 m, excavation step: 1 m. First layer of shotcrete is sprayed onto the face and the walls followed by installation of double IPE 240 steel ribs every metre. After that the wire mesh is installed. Second shotcrete layer 30 cm thick around the cavity is sprayed and stabilised by the steel ribs and wire meshes.

Note: placing of struts at 2-3 m max far from the face.

Fig. 3. Excavation process, Val di Sambro Tunnel, Italy (author's archive)

The construction process further comprises tunnel invert and kickers casting (execution of an invert excavation step, placing of the steel cages, casting of the tunnel invert and kickers), placing of the waterproofing consisting of a layer of geotextile and a PVC sheet, reinforcement cages installation and final lining casting (by using a formwork on wagon).

Notes:

- Repetition of the cycle until the 12 metres or 16 metres are excavated (the advance cycle can vary between 12 and 16 m)
- After the advance cycle is completed, a plug is carried out onto the face by means of 25 cm thick steel fibres shotcrete
- The final lining follows at 30 to 60 m from the face
- Advance rates are approximately 1.2 to 1.4 m of finished tunnel (already lined)
-

Time schedule of the advance cycle: Carrying out an advance cycle requires from 10 to 11 days:

- 5 days for the core-face reinforcement (drilling, insertion and cementation of 100 to 140 fiberglass tubes (7 at a time) 24 m long with the 12 m overlap if the advance cycle is 12 m, 8 m if the advance cycle is 16 m)
- 2 to 2.5 days to excavate from 6 to 8 m, including tunnel advance, mucking, installation of 6 to 8 steel ribs (2 IPE 240, step 1.0 m) with strut in the invert, shotcreting (30 cm thick)
- 12 hours for excavation, reinforcement and concreting of 6 ÷ 8 m kickers and invert (distance from the face always between 3 and 9 m in case of 12 m advance cycle, between 4 and 12 m in case of 16 m advance cycle)
- 2 to 2.5 days for the excavation of the remaining 6 to 8 m of the advance cycle
- 12 hours for excavation, reinforcement and concreting of the remaining 6 to 8 m of kickers and invert

CONCLUSION

Theoretical study and comparison of ADECO-RS and NATM methods defined basic assumptions and principles of both methods and set different approaches to tunnelling which have a major impact on the efficiency of the methods used in different conditions.

In the Czech Republic the New Austrian Tunnelling Method was a prevailing tunnelling method in past two decades. And so design and construction of the tunnel - where local conditions permit - should be tried out according to ADECO RS method.

The impact of advance core anchoring inclusion in statistical analysis and design of the tunnel itself could have a positive effect not only on the safety of underground works and the exposure of the excavation works on the surface, but also on the costs directly associated with the implementation of primary and secondary lining. The horizontal anchoring of the tunnel face may become a very suitable technological supplement reducing deformations of the excavated opening and the lining, as well as the magnitude of the settlement trough which makes it particularly suitable for shallow tunnels in urban areas.

ACKNOWLEDGEMENT

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OBSERVING LANDSCAPE CHANGES USING DISTANT METHODS

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ABSTRACT

Landscape changes are a very common phenomenon in the area of North-West Bohemia (the Czech Republic) as this area is heavy industrialized. This paper presents two methods for observing the landscape – the bathymetric mapping and the aerial mapping. The bathymetric mapping is used to reconstruct the original surface in area where the Nechranice dam was built in 1960' and to evaluate the sedimentation caused by the Ohře River. The original surface of the Ohře river canyon was reconstructed using old maps and the bathymetric mapping was performed with Lowrance HDS-5 Sonar. The aerial mapping introduced in this paper is a new method of using Small Format Aerial Photography in connection with an ordinary aircraft. The gimbal (camera stabilization) normally used by Unmanned Aerial Vehicles is mounted into a small aircraft and allowing the scanning of very large areas – in our case the open-pit mine Tušimice was the target of our study. The derived orthophoto and Digital Surface Models were used to complete the georelief development analysis based on old maps and aerial photographs.

KEYWORDS

North-West Bohemia, Nechranice dam, Bathymetric mapping, open-pit mine, aerial survey.

INTRODUCTION

Every minute the surrounding landscape changes. Heavy industrialization in connection with other human activities is changing land-use, georelief, settlement patterns and even river networks very quickly. Every year hundreds of hectares of land covered with new structures are transformed by open-pit mines or flooded by water dams. Such changes have happened in the past as well but on a much smaller scale. A very significant area influenced by these changes is the Ústí nad Labem region (the Czech Republic). This region has undergone dramatic changes in the past when brown coal mining started in the 1930s using open-pit technology. This had a destructive impact on the surrounding landscape – land-use structure has been completely changed, hydrological networks displaced and many towns and villages vanished. In this paper we would like to introduce two methods of observing landscape changes using distinct methods in the form of case studies. In the past years many studies using the Unmanned Aerial Vehicles (UAV) used as a spatial data collecting tool in order to record and analyse the landscape changes have been presented. Nowadays UAVs are becoming the standard tool for digital terrain model and orthophoto creation. The disadvantage of this tool is the relatively short range based on battery life (coverage of several hectares during one mission) and legislative restrictions. In this paper, we would like to present “UAV style” data collection with ordinary aircraft used as a carrier. The other distinct method presented in this paper is Sound Navigation and Ranging (Sonar) used to detect changes in dam-bottom within almost the same area of interest.

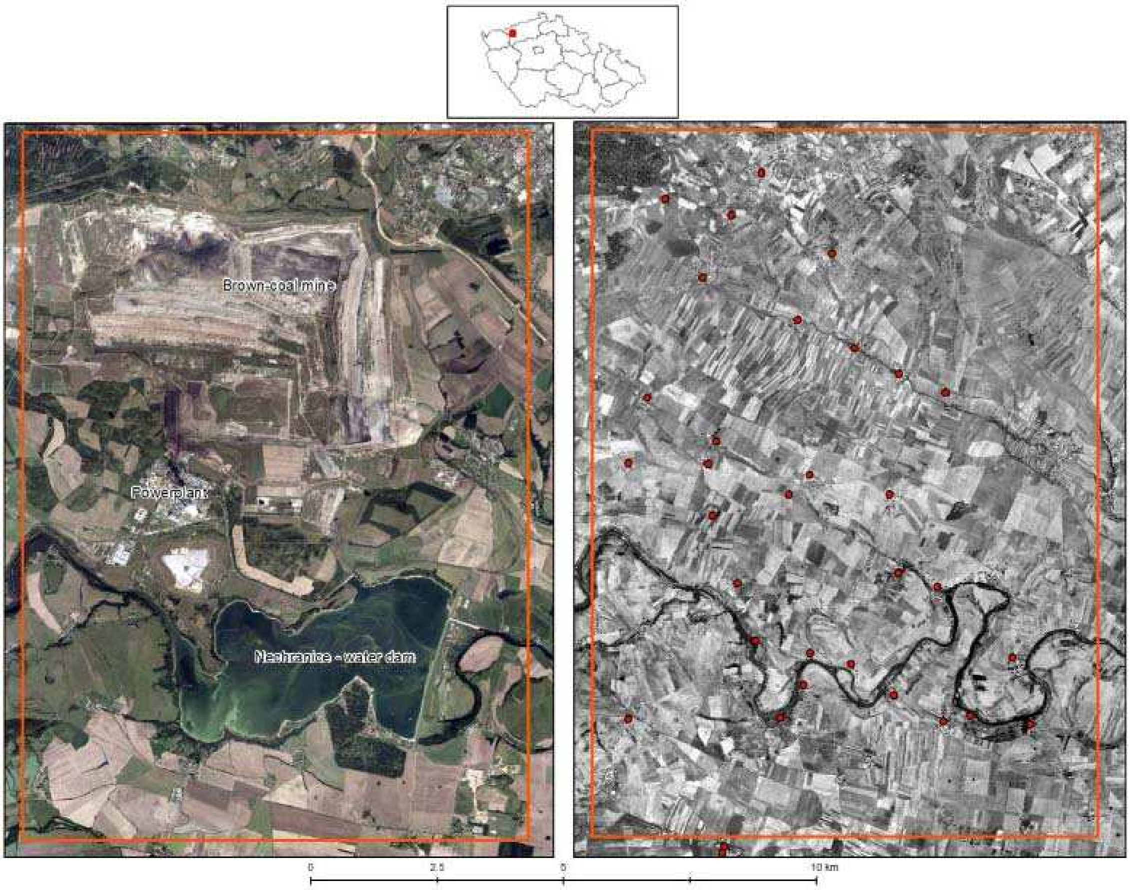

Fig. 1 - Area of interest overview. The current state (left). The original state visualized in a 1953 orthophoto (right). The red dots indicate extinct settlements in the area.

METHODS AND RESULTS

Area of interest

The area of interest is situated in the Ústí nad Labem region (North-West Bohemia, in the Czech Republic). Several areas were subject to perform the case studies in order to test and present the distinct methods for observing landscape changes [0]. All of the areas of interest have specific characteristics and different method requirements. A very significant area influenced by the human activity has been selected as so to present the not very common spatial collection methods. The area of interest is presented in *Fig. 1.*

The area of interest (140 km^2) is located in the south-west part of the Most brown coal basin in-between the towns Kadaň and Chomutov. The active brown-coal mine Nástup Tušimice covers approx. 14 km^2 and the water dam Nechranice 13.4 km^2. Brown coal mining in this region began at the end of the 18th century using the primitive ways of mining. Intensive open-pit mining started after World War II. In the 1960s – 1970s four large power plants were built in the close surroundings to the brown-coal source– Tušimice 1 (output 660 MW, shut down in 1998), Tušimice 2 (800 MW), Prunéřov 1 (440 MW) and Prunéřov 2 (1050 MW) [0], [0]. The water dam Nechranice (built in 1960) is situated ca. in the middle of Ohře river flow (103.4 km) and contains the total volume of 9.5 million m^3 (one of Europe's biggest rock fill dams) and as well as having the longest damming in the Central Europe (3280 m). The main purpose of this water dam is the water supply for the surrounding industry, power plants and large area irrigations. [0], [0]

Within this area of interest, the two methods of spatial data collection were tested – the Sonar method (bathymetric mapping) used to detect dam-bottom changes caused by the sedimentation process (Nechranice dam) and an aircraft "UAV-style" photogrammetry campaign focused on volumetric computations. The Sonar scanning was performed in cooperation with the Povodí Ohře Company (the owner of the dam). The photogrammetric imaging was tested upon the Severočeské doly's (the mining company) request.

A very detailed landscape development analysis, including hydrological network reconstruction and georelief development analysis was performed in this area as an initial point to the Nechranice dam bottom Sonar analysis (see [3] and [0]). Several old maps were processed in [0]. The oldest processed map is Müller's map of Bohemia (ca. 1720) followed by the 1st, 2nd and 3rd Military survey of Habsburg empire (1792, 1894, 1938). The Military survey presents the natural development of the area until heavy industrialization. This time-line is well supported by the Stabile cadastre maps (1842, 1:2880) containing detailed information about land-use. The time period of heavy industrialization is covered by State maps and State maps derived in the scale of 1:5000 (SMO-5) from the years 1953, 1972 and 1981.

The bathymetric mapping

The history of the bathymetric mapping in the Czech Republic is dated back into the end of the 19th century when the glacial lakes in the Bohemian Forest were mapped [0]. Bathymetry is the measurement of the depths of water bodies from the water surface. It's the marine equivalent to topography. Bathymetric surveys are generally conducted with a transducer which both transmits a sound pulse from the water surface (usually attached to a boat) and records that same signal when it bounces from the bottom of the water body. An echo sounder attached to the transducer filters and records the travel time of the pulse. At the same time that the pulse occurs, a GPS unit can record the location of the reading. After many of these readings are taken, corrections are made based on fluctuations in the water surface elevation that may have occurred during the survey. The individual points are then mapped - easily done in a GIS. [0]

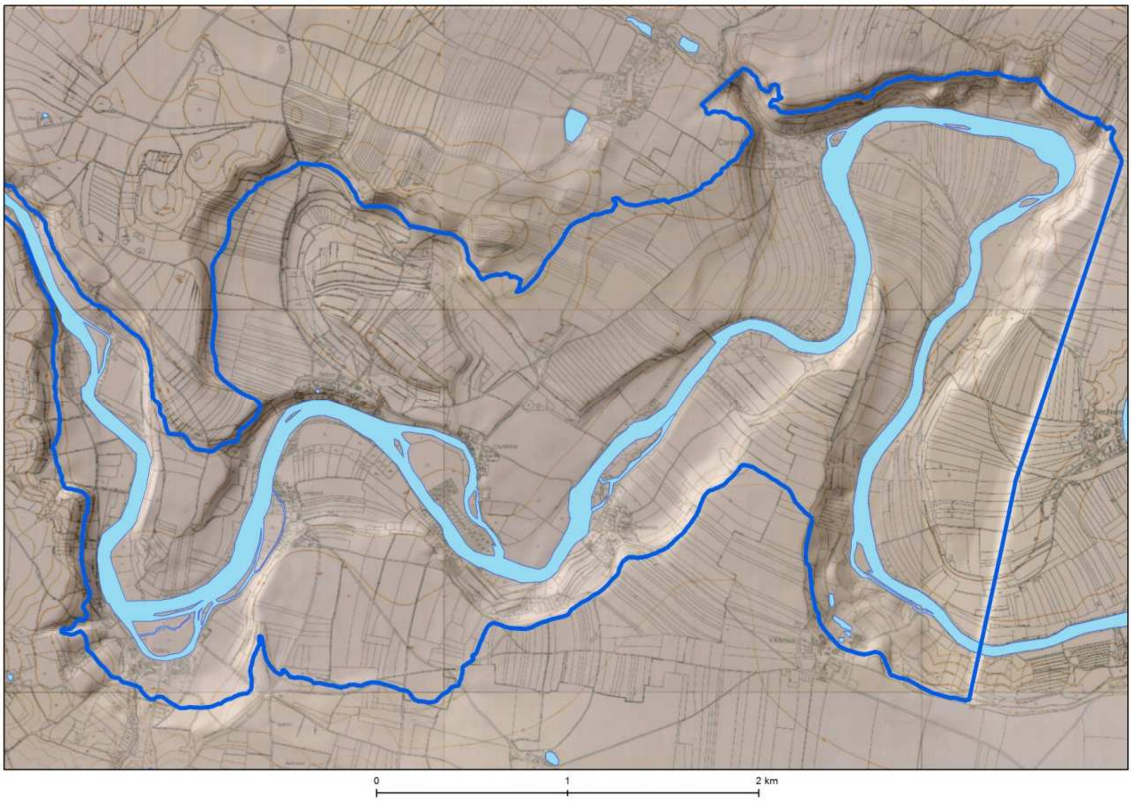

Fig. 2 The original Ohře river canyon derived from the SMO-5 (year 1953) maps

The purpose of our bathymetric mapping is to compare the original surface of the former river Ohře canyon and the current dam-bottom flooded more than 30 years ago. The analysis between these two DTMs could show the amount of sediment transported into the dam during the given years and other georelief changes caused by the dam's construction not contained in contemporary maps. It would be very interesting to identify the former Ohře riverbank.

In order to perform the dam-bottom development analysis, the original shape of the landscape is required. The oldest maps within the Ústí nad Labem region, with terrain represented by contour lines (with interval 5 to 20m), are the maps of the 3rd Military survey of the Habsburg Empire - renewed in 1930s. The renewed 3rd Military survey maps in scale of 1:25 000 do unfortunately cover the whole area of the Nechranice dam. Thus another map source used as the reference layer had to be chosen. The other important source of data for landscape reconstruction in the Nechranice water dam area is the derived state map in the scale of 1:5000 (SMO-5). The whole Czech Republic has been covered by SMO-5 maps since the year 1950. This map is not based on direct field measurements, but is derived from existing map sources. In these maps, elevation data are presented in the form of contour lines, elevation points and technical hachure. The base contour interval is 1 meter, 2 m or 5 m in addiction to base map elevation data [0]. Unfortunately the SMO-5 maps in this area contain contour lines with 10 m interval. This is (so far) the only data discovered in the map archives containing the elevation information prior to the dam's construction. The reconstructed Ohře river canyon is presented in *Fig. 2.*

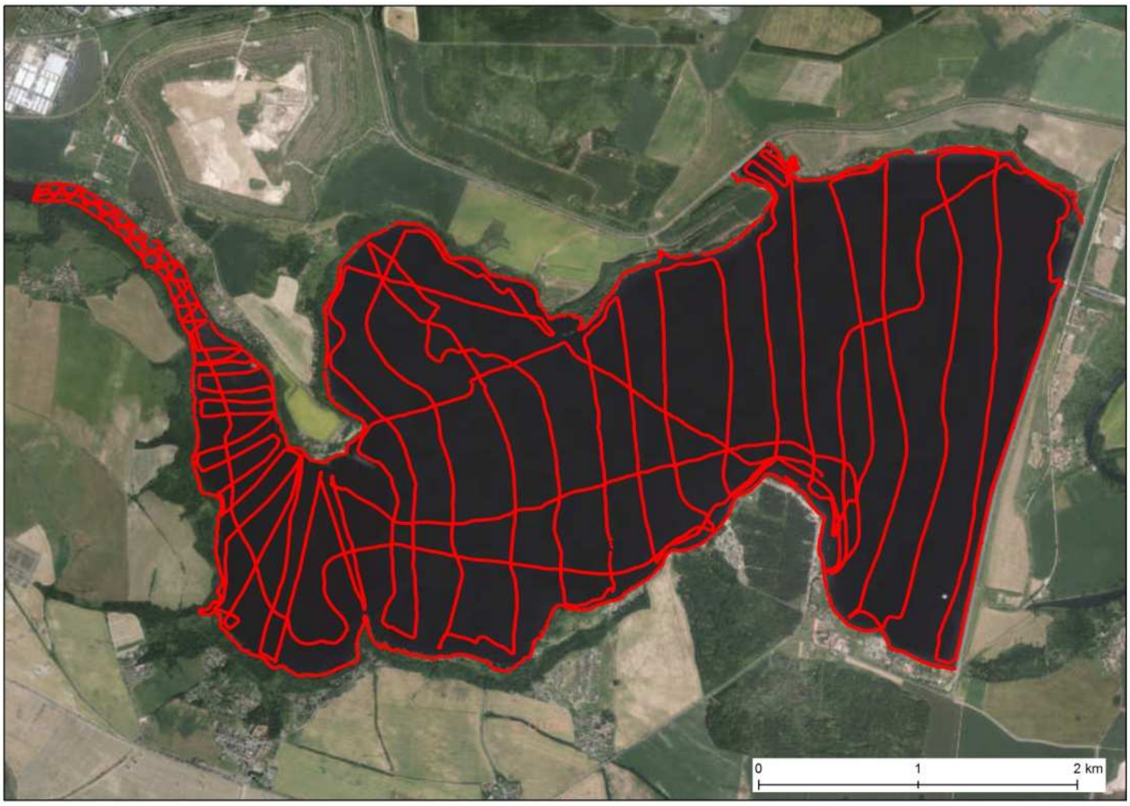

Fig. 3 Nechranice dam - transects scanned with Sonar

The bathymetric mapping of the Nechranice dam-bottom was performed in the summer of 2014 using the Lowrance HDS-5 Sonar and the boat owned by the water rescue service. The ideal speed for the bottom scanning is between 5 – 10 km/h and more than 40 transects across the water dam were scanned (the total length over 80km). The average distance in-between transects is about 250[1]m. The Sonar records the data as single points which can be further interpolated into a DTM. The scanner area is presented in *Fig. 3.*

[1] The shorter distance in-between the transects would produce results of higher quality, but with respect to the dam area and limited boat hire time we may consider these data satisfactory for desired analysis.

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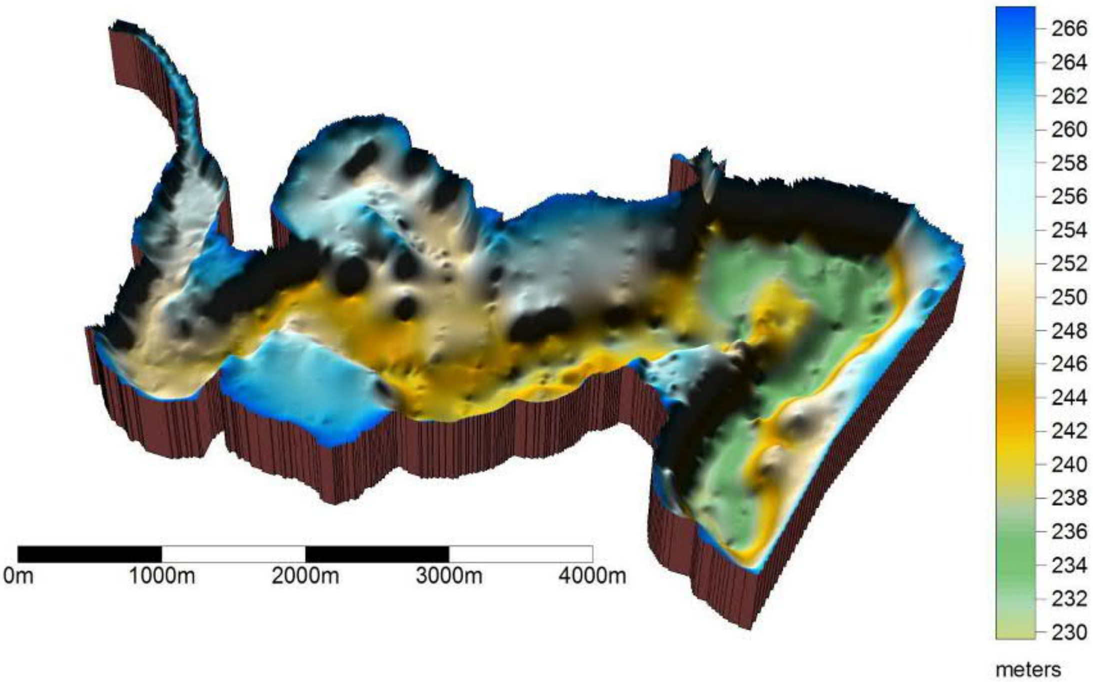

Fig. 4 Nechranice dam bottom reconstruction based on Sonar data

Data received from the bathymetric mapping represent the exact water depth in the place of acquisition. The actual water level was measured using the RTK GNSS receiver and was set to 266.75 m. The scanned points were interpolated into a DTM using *Topo to Raster* interpolation methods (implemented in ArcGIS) – see *Fig. 4.*

The differential analysis (see Fig. 5) shows the differences within the dam area. Many of the positive differences are the interpolation artefacts caused by the sparse data. There are three major differences visible in areas sufficiently covered with scanned data. Area 1 located in the Ohře river inflow is possibly caused by sediment deposition. Area 2 and 3 are the results of possible human activity prior to dam construction. All of these differences have to be analysed in the future.

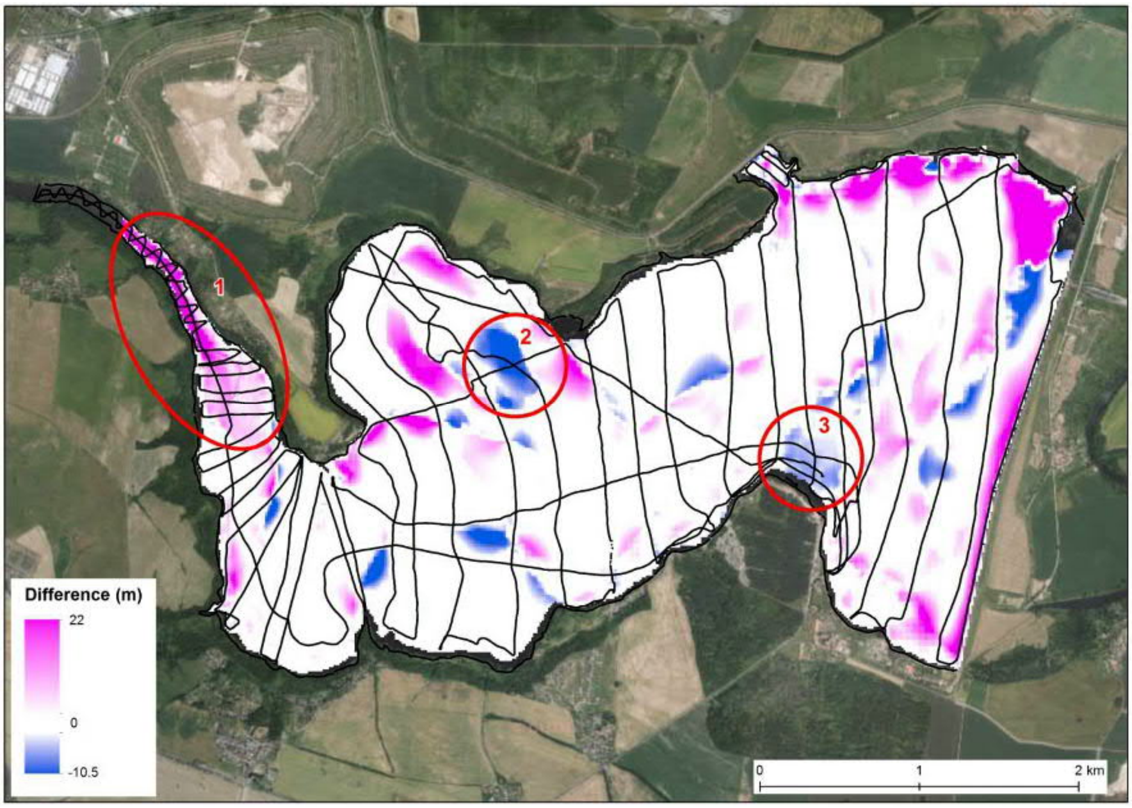

Fig. 5 Dam bottom differential analysis results

The aerial mapping

Georelief development analysis is the other task of our project. The reconstruction of the original landscape in the area of interest (Nechranice dam – Tušimice mine) is described in detail in [0].

Four different time-periods were reconstructed based on the input data. The original *untouched* georelief is derived using hand digitized contour lines from the SMO-5 maps – year 1953 and is presented already in the bathymetric mapping chapter. The second derived DTM is from the 1970s where the Nechranice water dam was already built and the Ohře river canyon flooded. The SMO-5 maps from the 1980s show the beginning of the brown-coal mining. A section of the Nechranice dam is missing as the original maps sheets were missing in the map archive. Nevertheless, there is no major change of the georelief in the missing section. The current state of the georelief is reconstructed using the DMR 4G data. These data represent a picture of nature or terrain modified by human activity in a digital form as heights of discrete points with X, Y, H coordinates in regular 5 x 5 m grid. These data were obtained using LIDAR technology [0]. The resulting DTMs for the year 1953 and 2012 are presented in

Fig. 6.

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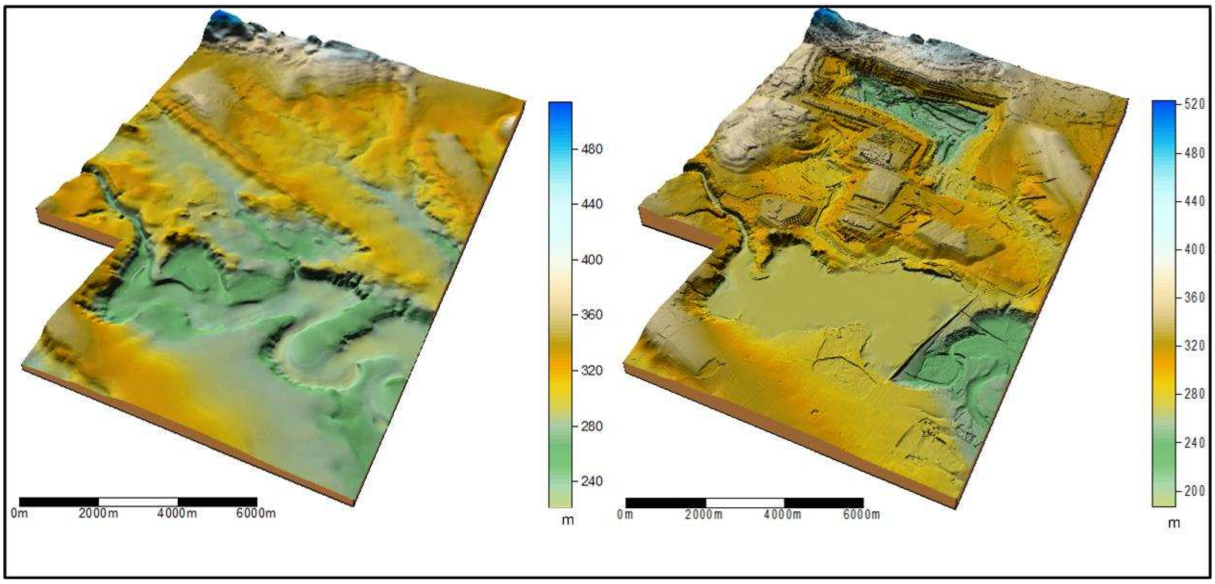

Fig. 6 Georelief reconstructions of the area of interest

The Tušimice open-pit mine is expanding every minute towards Chomutov (the neighbouring town) and precise data describing the volumes of the transported material are required. The open-pit mine is regularly surveyed by a photogrammetric company using an aircraft flying at about 1 km altitude. This method is expensive and weather dependent. In the autumn – winter – early spring period, the whole area is commonly covered with fog for several weeks and the standard way of photogrammetric survey can't be applied.

In the autumn of 2014, cooperation with the Severočeské doly, a.s. and Vršanská uhelná, a.s. began to test the possibilities of UAV mapping of the desired mining areas. The advantage of UAV mapping over standard photogrammetric surveying is the flexibility and much lower flying altitude. This method can be thus used during foggy days. The disadvantage of UAV mapping is the range and the required presence at the surveyed site. According to Czech civil aviation regulations, one can operate the UAV (drone or the fixed-wing solution) under manual or automatic flight only:

- The *manual* flight means that the pilot operates the UAV during the whole flight. This method is suitable for taking oblique photography of for shooting videos.
- The *automatic* flight is suitable for surveying larger areas within the direct sight of the pilot. The UAV follows the planned mission, assuring the coverage (and overlap) of the images. During the automatic flight the pilot MUST HAVE visual contact with the UAV and must be capable of taking control over the UAV at any minute. This means that large areas, like the open-pit mines, would be cumbersome to survey with UAVs. The desired surveyed area is about 900 hectares.
- An *autonomous* flight using a fixed-wing UAV is the best solution for such large areas. The UAV flies along with the planned mission outside of the pilot's sight and returns when the mission is accomplished. The fly time ca. 40 minutes per battery is suitable for surveying such large areas. This method is NOT allowed to be used in the Czech Republic.

Based on these facts a new method using a small aircraft for Small Format Aerial Photography was developed [0]. Many studies ([0], [0] and [0]) have proved that the classic compact cameras preciseness for close-range (aerial and earthbound) photogrammetry is, in comparison with professional aerial cameras, sufficient for the given tasks (DSM creation, orthophoto).

This method uses the same gimbal (camera stabilization) as the drone. A special mount was developed allowing the placement of the gimbal into the aircraft and shooting time-lapse images. The Nikon D3X camera in combination with a Sigma 35mm f/1.4 DG HSM Nikon lens was used in the test survey. The average flight altitude was 200 m, flight speed 90 km/h and images were shot every second assures about 90% image overlap (see *Fig. 7*). The imagery side-lap was estimated to be 70 – 80% assuring the resulting model complexity. The spatial resolution of the produced DSM (Digital Surface Model) and orthophoto may be up to 5 cm/pixel. The test area is fully covered with ground control points (GCP) normally used for photogrammetric survey and densified by additional GCPs.

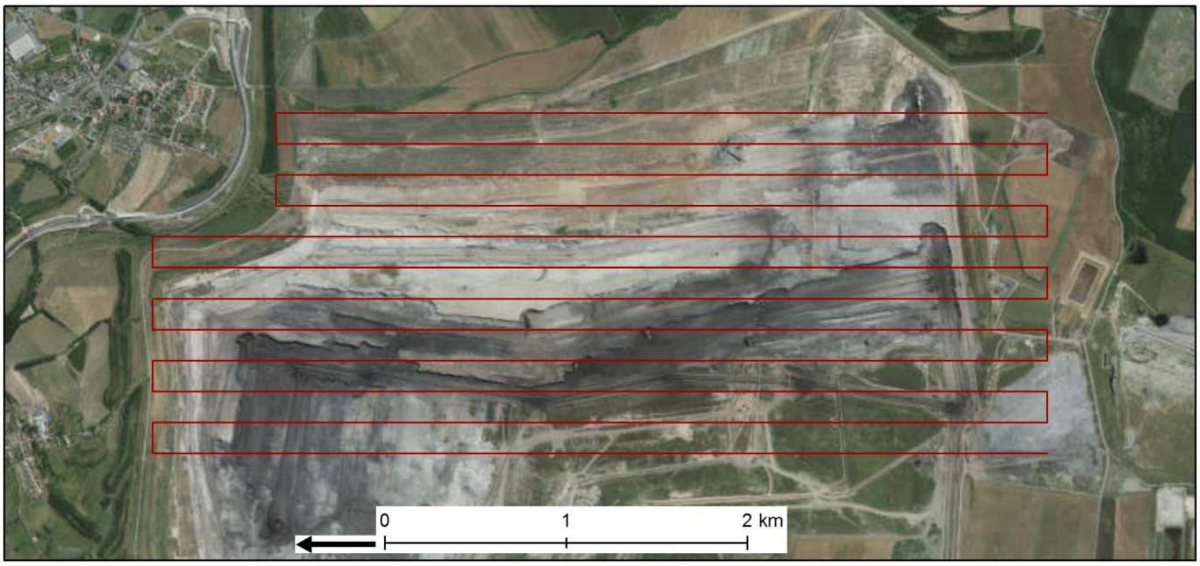

Fig. 7 The flight plan over the Tušimice open-pit mine

The images are processed in PhotoScan (Agiosoft LLC) software. The detailed processing workflow is introduced in [0]. The total amount of processed images was in this case 2400. The results are currently subjected to statistical tests that should prove the accuracy of the resulting 3D models. An overview of the results are presented in *Fig. 8.*

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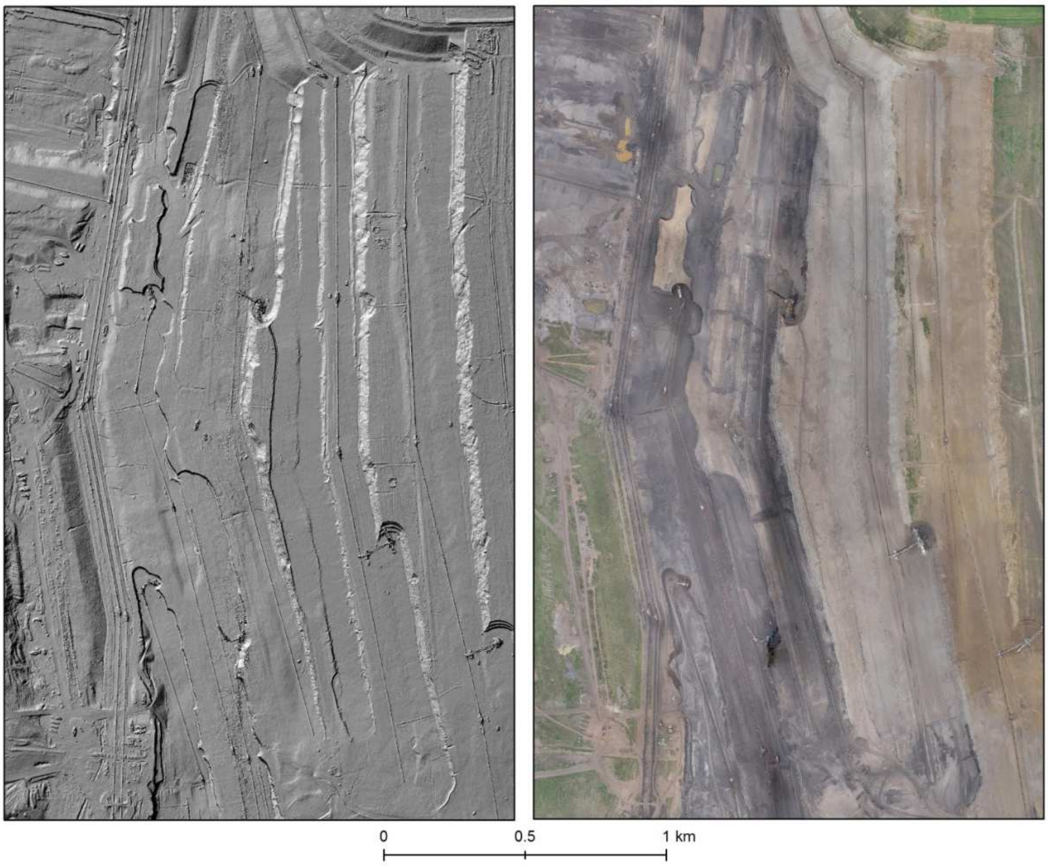

Fig. 8 The resulting DSM and orthophoto of the Tušimice open-pit mine

CONCLUSIONS

In this paper, methods offering a new point of view on the landscape changed by human activity are presented. The bathymetric mapping performed on the Nechranice dam discovered very thick (10 – 15m) sediment layer in the underwater fan at the Ohře river inflow area. The sediment research is the future scope of this project. Materials contained in the sediments (small particles, pollen) may show the human activity impact on the surrounding landscape. The data processed within this area of interest are accessible at http://mapserver.ujep.cz/Projekty/NAKI_mapy/Nechranice/.

The method of the "UAV-style" aircraft data collection seems to be a very reasonable way of close-range photogrammetry application on large areas. The image and the resulting 3D models quality seems to be sufficient for the mining company requests. The statistical data quality evaluation will be performed on these datasets. The DSM and the orthophoto compared with other data sources are accessible at http://mapserver.ujep.cz/Projekty/Ukazky/Tusimice/ and the 3D model visualization is published at https://skfb.ly/BTpv.

ABBREVIATIONS

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DETECTION OF NONSTATIONARITIES OF SEVERAL SMALL CZECH RIVERS BY STATISTICAL METHODS

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ABSTRACT

The paper presents some results of a research devoted to a statistical analysis of discharges in pilot catchments in the Czech Republic with the aim to detect changes in their stochastic behaviour that might be caused by climate changes. The nonstandard statistical methods are applied to detect changes in annual means as well as in seasonal behaviour of runoffs series.

KEYWORDS

Climate change, discharges, statistical methods, changes in annual means, changes in seasonal behaviour.

INTRODUCTION

An impact of global warming on hydrological variables is often discussed in papers on climate change, see [1] or [2] among others. Many papers present a prediction of future discharges for large European rivers using climatological and hydrological models, see e.g. [3], [4]. [5] and [6]. The same approach for several Czech rivers has been applied by [7]. Results obtained by hydrological models are indeed interesting but we may also be interested in the question whether the real discharge series exhibit some changes that might be attributed to climate change. To answer this question historical records are analysed by statistical methods, see for example [8] or [9]. In last twenty years many new statistical procedures known under the name statistical change-point detection methods have been developed for studying stationarity of time series and applied to climatological data, see e.g. [10] or [11].

Studying stationarity of discharge series by statistical change point detection methods has a long history. One of the first applied papers in this field was devoted to detection of change in the mean of the Nile river annual mean discharges, see [12]. Nevertheless, applications of statistical procedures for detecting changes in stochastic behaviour of temperature series are much more frequent than applications studying homogeneity of discharge series. A large variability of discharge series in comparison with their relatively shorter length may cause that the statistical procedures are not able to detect trends or changes even if there might be some, see [13] and [14]. Moreover, there are only very few streams not affected by construction of reservoirs or dams.

The usual aim of a statistical analysis is to detect trends and changes in annual or monthly means time series, while statistical inference based on daily means is less frequent. However, in case we are interested in changes in extremes (floods or draughts) or changes of seasonal behaviour, then an analysis of daily values is necessary. The aim of our paper is to apply change-point methods suggested by [15] to detect changes in stochastic behaviour of runoffs of several Czech rivers.

In our pilot study we analysed annual as well as daily mean discharge series of several small Czech rivers that are practically not affected by human activity. In such a case the changes detected in their stochastic behaviour are most probably caused by climate change. The data were analysed from a hydrological point of view by [16], [17], [18] and [19] in the scope of a grant KLISPO, supported by the National agency of the research in Agriculture, Ministry of Agriculture, Czech Republic (2007-2011). The research project KLISPO was mainly focused to following three questions: – question of the reliability of supply purpose of water management reservoirs under new climate conditions, – question of contrary requirements of supply and retention (flood protection) purposes of reservoirs including economical aspects and efficiency, – question of operational safety of hydraulic structures and dams in new changed hydrological conditions. In the part devoted to stationarity of studied discharge series the authors conclude that in several cases some important characteristics, e.g. 50 years return levels, have changed. However, they also conclude that these changes have no a general trend that entitles us to apply results obtained from one station to all stations or at least to some area. Therefore, they suggest analysing all discharge series separately. Finally, they conclude that a prediction of future behaviour for 50 coming years is not reliable.

The analysed discharge series are presented in *Tab 1*. The first column gives the name of the river together with the name of the station. The second and the third columns present the time span when the observations were available and the fourth column gives the years when the data were missing. The fifth column shows the number of the years for which the data were analysed. We would like to mention here that we worked with calendar years, i.e., any year started January 1st and ended December 31st. Moreover, we omitted the data corresponding to February 29nd so that we had 365 daily values for every year. *Fig. 1* shows the positions of all stations whose discharge series were analysed.

Tab. 1. Name of rivers, stations, beginning and the end of measurement, missing years, number of analysed years.

river	beginning	end	missing years	number
Bělá – Kvasiny	1941	2007		67
Blanice - Bl. Mlýn	1953	2008		56
Brodečka-Otaslavice	1941	2007		67
Čeladenka - Čeladná	1953	2007		55
Doubrava - Spačice	1952	2006		55
Jizerka – Dolní Štěpanice	1923	2008		86
Kyjovka - Kyjov	1951	2008		58
Morava -Vlaské	1950	2008		59
Mumlava – Janov - Harrachov	1941	2008		68
Divoká Orlice – Klášterec nad Orlicí	1938	2006		69
Otava - Rejštejn	1911	2007	1920 - 1930	75
			1937 - 1947	
Porubka - Vřesina	1953	2008		56
Rož. Bečva - H. Bečva	1955	2008		54
Svratka - Borovnice	1925	2007		67
Úpa - Horní Maršov	1931	2006	1940 - 1948	67
Vlára - Popov	1956	2008		53
Vydra - Modrava	1931	2007	1940 - 1948	68
Zdobnice –Slatina nad Zdobnicí	1945	2007		63

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Fig. 1. Positions of analysed sites.

STATISTICAL METHODS FOR ANALYZING STATIONARITY

Change in annual means

Any study of stationarity of discharge series usually starts with an analysis of annual mean runoffs with the aim to detect a possible change in their mean value. The mean of the studied series may change in many ways but we are mainly interested in detection of a monotone trend. In the scope of mathematical statistics decision problems are solved by hypotheses testing. We may start with two most simple tests: a test for existence of a linear trend and a two-sample test for equality of two means. In the second test we split the series into two parts – before and after a subjectively chosen year and we test whether the mean before and the mean after this chosen year are equal. Observing the values of the annual means $X(t_1), \ldots X(t_n)$ the test statistic for the first test has the form

$$T_{tr} = \frac{\sum_{i=1}^{n} X(t_i)(t_i - \overline{t})}{\hat{\sigma}\ \sqrt{\sum_{i=1}^{n}(t_i - \overline{t})^2}} ,$$

where $\hat{\sigma}$ denotes the usual estimate of errors standard deviation based on a residual sum of squares and the test statistic for the second test has a form

$$T_f(k) = \sqrt{\frac{k\,(n-k)}{n}}\ \frac{(\overline{X}_1 - \overline{X}_2)}{s} ,$$

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k denotes an order of the splitting year, $\overline{X}_1 = \sum_{i=1}^{k} X(t_i)/k$, $\overline{X}_2 = \sum_{i=k+1}^{n} X(t_i)/(n-k)$, $s = \{ (\sum_{i=1}^{k}(X(t_i) - \overline{X}_1)^2 + \sum_{i=k=1}^{n}(X(t_i) - \overline{X}_2)^2)/(n-2)\}^{1/2}$. Under the null hypothesis claiming that there is not a change, the statistics T_{tr} and T_f (k) have a Student distribution with n-2 degrees of freedom. Supposing the two-sided alternative and taking the significance level equal to α, we reject the null hypothesis if the absolute value of the considered test statistic is larger than α/2 % upper quantile, i.e., (1- α/2) % quantile of a Student distribution with n-2 degrees of freedom. The first test has a largest power if there is a linear trend in the mean, while the second one if there is a sudden shift in the mean. On the other hand, the both tests are often able to detect any monotonic trend, but indeed with a smaller power.

As we mentioned before, for a two-sample test we have to decide how to split the series. In our applications bellow we have split the series after the year 1997. If we do not wish to split the series in a specifically chosen year we can take a change-point analysis approach, for more details see [20]. In change point analysis we calculate a value of a two-sample test statistic for any time point (for any year that splits the series) so that instead of obtaining one value of a test statistic only, we get a sequence of values of test statistics, i.e., for any possible time point (any year) we have one value. Then our final test statistic is either a maximum, i.e., $max_k\, T_f(k)$, or a mean, i.e., $\sum_k T_f\,(k)/n$ of two-sample test statistics. Often also a maximum or mean of the weighted test statistics, where the weights are chosen to be $w_k = \{(k/n)\ (1-k/n)\}^{1/2}$, k=1,…,n-1 serve as test statistics.

Exact critical values of the introduced change-point test statistics are unknown but we can use critical values obtained by a so-called permutation principle. Permutation test was suggested by Fisher in 1930 and it has been successfully applied for many two-sample tests. [21] showed that it is possible to apply the permutation test for change-point problems as well. The permutation approach consists in combining two-samples together and randomly permuting the combined sample many times. Then, for every permuted sample a value of the considered test statistic is computed so that a large set of values is obtained where their number corresponds to the number of performed permutations. An α% upper empirical quantile may serve as a α% critical value of the test.

Change in mean annual cycle

It is not only mean of annual mean discharges that may change in time but also a mean of annual cycles. An annual cycle may be represented by a hydrogram of daily mean values for one calendar year, i.e. by a vector of 365 daily values, supposing that the 29 February values were omitted. We may be interested whether a mean vector of these vectors remains the same over the observation period.

The test statistic that may be applied for testing equality of two mean vectors has the form

$$W(k) = \frac{k(n-k)}{k} (\overline{\boldsymbol{X}}_1 - \overline{\boldsymbol{X}}_2)^T \hat{\Sigma}^{-1} (\overline{\boldsymbol{X}}_1 - \overline{\boldsymbol{X}}_2),$$

k denotes an order of the splitting year, $\overline{\boldsymbol{X}}_1 = \sum_{i=1}^{k} \boldsymbol{X}(t_i)/k$, $\overline{\boldsymbol{X}}_2 = \sum_{i=k+1}^{n} \overline{\boldsymbol{X}}(t_i)/(n-k)$, and $\hat{\Sigma}$ is a pooled sample covariance matrix. The test statistic W(k) is a so-called Hotelling test statistic. After a proper standardization it has a F distribution with m and n-2 degrees of freedom with m denoting a dimension of the analysing vectors, for more details see [22].

The problem is highly dimensional and it is difficult to look for a change in at least one of 365 components. Therefore, it is convenient to reduce the dimensionality of the problem by replacing every “year” vector by a smaller number of parameters. [15] recommended replacing the 365-dimensional vectors by $2L$ coefficients of the Fourier series expansion approximation with L smallest Fourier frequencies or by K scores of the method of principal components. Using both methods [15] showed that for European rivers using Fourier series approximation the good choice is to take L =1, 2, 3 (2 L parameters) or to take $6 \leq K \leq 12$ for the method of principle components. Instead of testing equality of means of two 365-dimensional vectors we test equality of means of two vectors with either 2 L or K dimension. There is another natural method for analysing annual cycles. It replaces a vector of daily averages by a vector of monthly averages. In this case we look for a change in mean of 12-dimensional vector and the test statistic $W(k)$ may be again applied.

We may be interested why the method of the principal components approximation may be suitable for detecting a possible change. The reason is that we consider the linear combination of the original daily values where the “larger” weights are given to the coordinates that have a larger variability and this larger variability may be caused by the change in their mean. This was proved by [23]. The method of the Fourier series approximation may be suitable if annual cycles may be relatively well approximated by a Fourier series with the smallest Fourier frequencies. As the annual cycles are almost periodic functions with one or two peaks the approximation by a Fourier series may be quite good.

For the corresponding change-point problem we may use either a maximum or a mean of the statistics $\{W(k)\}$, respectively a maximum or a mean of the weighted statistics $\{w_k W(k)\}$ with the weights $w_k = k(n-k)/n^2$. In our paper we consider:

$$\max_k W(k), \qquad \max_k w_k W(k) \qquad \text{and} \qquad \sum_{k=1}^{n} w_k W(k)/n.$$

The approximate critical values and the corresponding p-values may be again obtained by the permutation principle.

RESULTS OF STATISTICAL TESTS

Annual means

We have applied three tests – a test for existence of a linear trend, a test comparing a mean in the period before the year 1997 with a mean after the year 1997 and a change-point test for detection a change in the mean value. The year 1997 was chosen subjectively to compare the last ten years of measurement with the previous period. Considering a significance level $\alpha = 0{,}05$, no linear trend in mean annual averages was detected. Comparing the mean of the period before the year 1997 and after it, an increase of annual mean discharge has been detected for the Mumlava river (p-value is smaller than 0,001), see *Fig. 2*. If the change-point test has been applied then in addition to the Mumlava river (with all p-values smaller than 0,01) the Kyjovka river exhibits a significant change (a decrease) that started after the year 1971 (with all p-values smaller than 0,01). The Jizerka river is the longest analysed river and the tests showed that the change occurred in the beginning of measurements. Moreover, the p-values for the change-point analysis using all three test statistics (maximum, maximum of weighted statistics and mean of weighted statistics) are between 0,01 and 0,03. It means that choosing $\alpha = 0{,}01$ instead of $\alpha = 0{,}05$ the null hypothesis would not be rejected. Therefore, we may have some doubts whether there was a change or not.

We conclude that for two rivers (the Mumlava, the Kyjovka) a statistically significant change in mean has been detected at the significance level $\alpha = 0{,}01$ and for one river (the Jizera) at the significance level $\alpha = 0{,}05$. *Fig. 2* represents the behaviour of annual mean discharge series of the Mumlava and Fig. 3 represents the same discharge series of the Kyjovka.

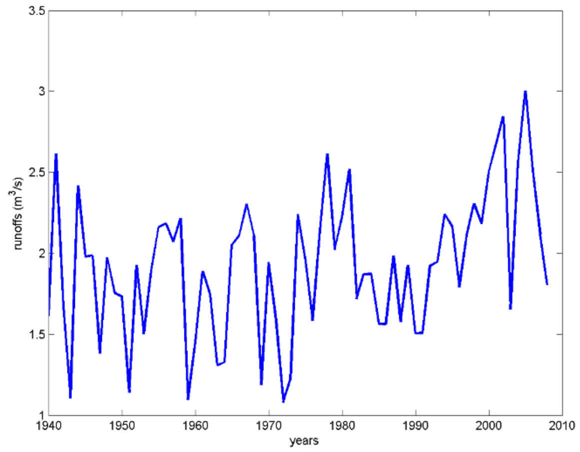

Fig. 2. Annual means of the Mumlava runoffs (m^3/s) in Harrachov.

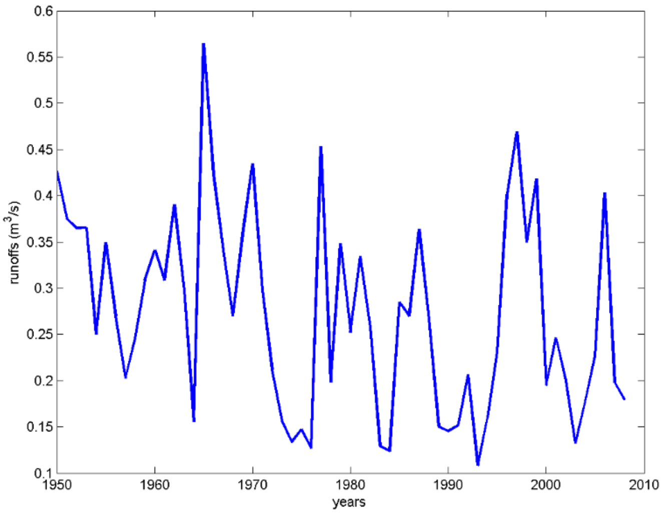

Fig. 3. Annual means of the Kyjovka runoffs (m^3/s) in Kyjov.

Annual cycles

For the first analysis we again split the series into two parts, i.e., before the year 1997 and after it. We applied three methods – method of principal components approximation, method of the Fourier series approximation and the method of monthly means. For the method of the principal components approximation we compared means of $K=5$ scores, for the method of the Fourier series approximation we compared $2\ L=6$ Fourier coefficients. *Tab. 2* shows the values of the test statistics computed for all three methods together with their p-values computed from the F distribution. We present the results for those rivers where at least one of computed p-values fall under 0,1. We conclude that (with an exception of the Vydra) p-value of at least one of the tests is smaller than

0,05. Moreover, there are only two rivers (the Jizerka, the Morava) where the *p* value of one test is small while the *p* values of two other methods are relatively large. For all other rivers the results of all tests are in agreement.

Tab. 2. Values of test statistics with corresponding p – values for all three methods when we split the series in 1997

river	**prin.comp. test.stat.**	**p-value**	**Fourier. expan. test.stat.**	**p-value**	**monthly mean . test.stat.**	**p-value**
Blanice	19,54	0,007	19,6	0,015	35,58	0,02
Jizerka	11,01	0,074	6,79	0,391	30,02	0,022
Morava	17,04	0,014	6,03	0,490	23,76	0,126
Mumlava	21,60	0,074	10,7	0,149	71,55	0
Orlice	10,94	0,083	11,92	0,106	29,78	0,034
Otava	15,44	0,019	11,19	0,126	32,67	0,016
Vydra	11,34	0,072	13,48	0,069	25,21	0,08

Interpreting the results of a change point analysis is more difficult. We applied for all three methods three test statistics. *Tab. 3* presents a number of rejections at the significance level $\alpha = 0,1$ together with the upper bound of the *p* – values for all three methods for those stations where the null hypothesis of stationarity has been rejected at least once at the significance level $\alpha = 0,1$. We may again conclude that for the Blanice and the Mumlava stationarity of seasonal behaviour has been clearly rejected. It seems plausible that seasonal behaviour of the Jizerka, the Morava, the Otava and the Vydra is also nonstationary. It is interesting to see that the results of change-point analysis agree quite well with the results of two-sample analysis. That indicates that the statistical significant change in seasonal behaviour most probably occurred around the year 1997 or in the other words seasonal behaviour has changed for many stations in last 8 -12 years of observations.

Tab. 3. Number of rejections at a significance level α=0,1 for all tests and all three methods when change point analysis has been applied.

river	**prin.comp.**	**Fourier.exp.**	**monthly means**
Blanice	3 (< 0,01)	3 (< 0,005)	2 (< 0,06)
Čeladenka	0	0	1 (< 0,05)
Doubrava	0	0	1 (< 0,08)
Jizerka	2 (< 0,1)	2 (< 0,1)	2 (< 0,06)
Morava	2 (< 0,05)	0	2 (< 0,02)

Mumlava	3 (< 0,05)	3 (< 0,03)	3 (< 0,01)
Orlice	0	0	1 (< 0,1)
Otava	1 (< 0,05)	3 (< 0,05)	3 (< 0,9)
Vydra	3 (< 0,05)	3 (< 0,1)	1 (< 0,03)

BASIC FEATURES OF NON-STATIONARY BEHAVIOR

Unfortunately, the above described statistical methods do not indicate the main causes of potentially nonstationary seasonal behaviour. To understand better these features we present *Fig. 4 – 9* of the smoothed annual mean cycle before 1997 and after it for all rivers where the null hypothesis of stationarity of a mean annual cycle has been rejected. (We smoothed the means by a kernel smoothing technique using the Epanechnikov window with a bandwith h_n =0,05).

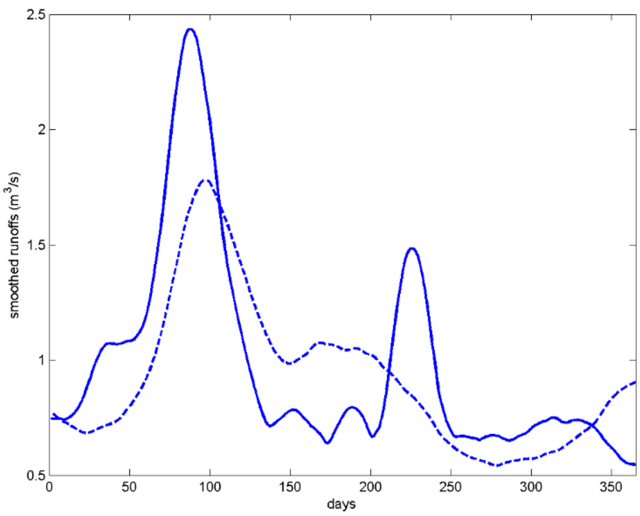

Fig. 4. Blanice - smoothed annual cycle of runoffs (m^3/s) before the year 1997 (dashed line) and after the year 1998 (solid line).

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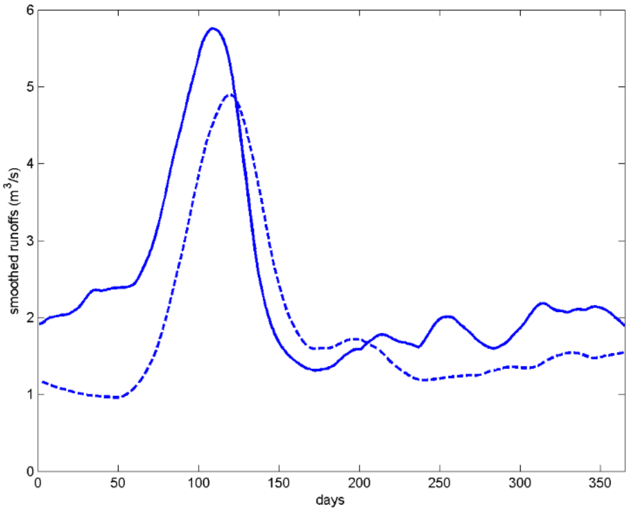

Fig. 5. Mumlava - smoothed annual cycle of runoffs (m^3/s) before the year 1997 (dashed line) and after the year 1998 (solid line).

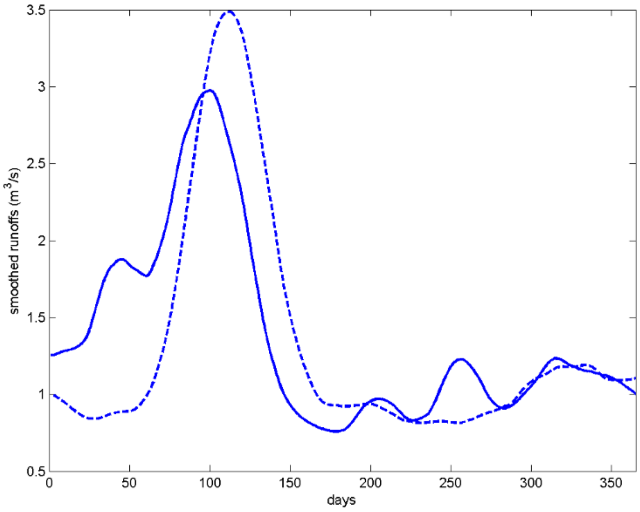

Fig. 6. Jizerka - smoothed annual cycle of runoffs (m3/s) before the year 1997 (dashed line) and after the year 1998 (solid line).

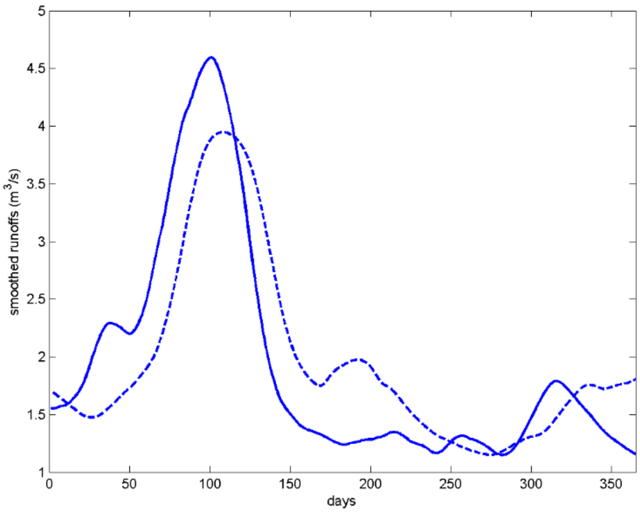

Fig 7. Morava - smoothed annual cycle of runoffs (m³/s) before the year 1997 (dashed line) and after the 1998 (solid line).

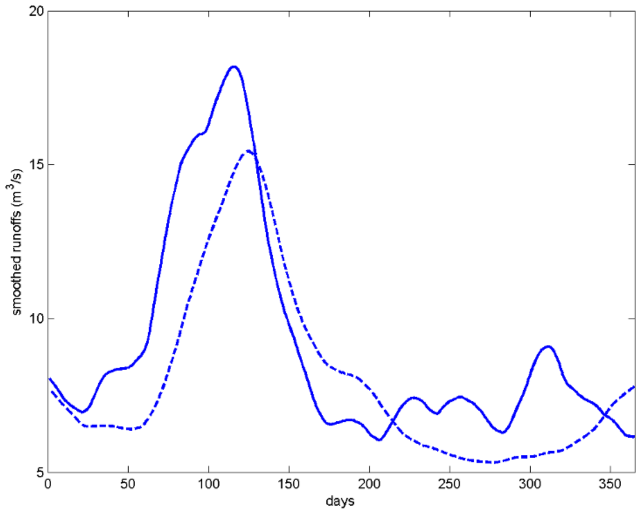

Fig 8. Otava - smoothed annual cycle of runoffs (m³/s) before the year 1997 (dashed line) and after the year 1998 (solid line).

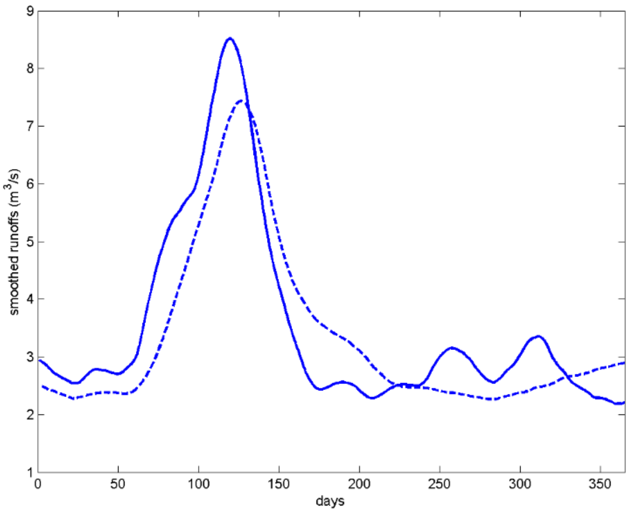

Fig 9. Vydra - smoothed annual cycle of runoffs (m^3/s) before the year 1997 (dashed line) and after the year 1998 (solid line).

Despite the differences in seasonal behaviour of all presented rivers, we may see some common features. In the period after 1998 the timing of spring high discharge is shifted to the beginning of the calendar year and moreover the winter runoffs are generally higher than in the period before 1997.

We calculated a set of locations (days) of annual maxima for the period before 1997 and after it. *Tab. 4* presents medians, lower and upper quartiles of these two sets. We see that with a very few exceptions all these locations characteristics for a period before 1997 attain larger values. The same is true if we calculated locations of annual maxima for smoothed versions of annual cycles.

Tab. 4. Medians, lower and upper quartiles of locations (days) of spring maximal discharges for the period before 1997 and after the year 1998.

River	**-1997 median**	**1998 - median**	**-1997 low.quartile**	**1998- low.quart.**	**-1997 upp.quart.**	**1998- upp.quart.**
Bělá	84	70	56,5	44	102	90
Blanice	121	78	80	60	165,5	89,7
Brodečka	86	81,5	59	63	124,2	88
Čeladenka	103	76	82	68	138,2	100
Doubrava	84,5	69	56	32,5	117	80,5
Jizerka	104	68	91,5	26,5	119,5	89,5
Kyjovka	112	83	62,5	29	146,5	133,5
Morava	101	67	79	31	123	86,2
Mumlava	112	68	98,7	26,5	127,2	87,5
Orlice	85	72	54,5	61,2	101,5	88,75
Otava	104	74	76,5	44	128,7	81
Porubka	95	78	70	29,5	136	103,2
Bečva	90	71	72	61,7	135,5	86
Svratka	79	65,5	48,5	44	112,7	78
Úpa	113	93	99	61,7	127	103,5
Vlára	77	61	52	37,7	111	87,2
Vydra	113,5	74	90	44	133	81
Zdobnice	84	70	55	43	102,2	88

For every year and all the rivers we also calculated mean runoffs for the period January-February. *Tab. 5* presents medians, upper and lower quartiles for the period before 1997 and after. With some exceptions the statistical location characteristics of “winter runoffs” are for the period after the year 1998 larger than for the previous period. This might be caused by relatively warmer winters in this period.

Tab 5. Medians, lower and upper quartiles of mean discharges of January-February for the period before 1997 and after the year 1998.

River	-1997 median	1998- median	-1997 low.quart.	1998- low.quart.	-1997 upp.quart.	1998- upp.quart.
Bělá	0,9893	1,189	0,659	0,979	1,428	1,574
Blanice	0,696	0,861	0,447	0,617	0,941	1,309
Brodečka	0,285	0,503	0,165	0,336	0,513	0,631
Doubrava	1,887	2,497	1,084	1,602	3,005	3,537
Čeladenka	0,441	0,656	0,309	0,401	0,665	0,816
Jizera	0,745	1,377	0,539	1,023	1,163	1,819
Kyjovka	0,212	0,247	0,159	0,193	0,335	0,257
Morava	1,566	1,702	1,002	1,444	2,100	2,224
Mumlava	0,914	1,936	0,602	1,649	1,39	2,729
Orlice	3,09	3,899	1,825	2,871	4,14	4,988
Porubka	0,214	0,209	0,162	0,144	0,306	0,270
Bečva	0,226	0,281	0,120	0,177	0,353	0,357
Svratka	1,714	1,895	0,893	1,469	2,349	2,644
Úpa	1,493	1,488	1,140	1,194	1,793	1,658
Vlára	1,787	1,912	1,217	1,794	2,617	2,484
Vydra	2,25	2,464	1,523	1,970	2,978	3,687
Zdobnice	1,957	2,215	1,149	1,648	2,900	2,726

CONCLUSION

In the last time many hydrologists and climatologists have tried to predict future behaviour of run-offs series with the help of different climate scenarios. Our goal was to perform a statistical analysis of real data, i.e., annual and daily mean values to detect changes in their stochastic behaviour. We studied non-stationarities of several small Czech rivers discharge series using a two-sample test for equality of means of variables and vectors and its change point analogue. Stationarity of annual mean discharge series has been rejected for the Kyjovka and the Mumlava. Further, we applied the statistical tests to detect non-stationarities in seasonal cycle described by daily mean run-offs. As the vectors of daily values have too many components we replaced them by vectors of Fourier coefficients, vectors of principal components scores or vectors of monthly means. The tests detected a change in seasonal behaviour of the Blanice and the Mumlava (with very small p values) and of the Jizerka, the Morava, the Otava and the Vydra (with relatively small p values). For the Čeladenka, the Doubrava, the Orlice the non-stationarity of seasonal behaviour is ambiguous. In most cases the change consists in shift of spring peak run-offs and increase of winter (January-February) discharge.

As we could see there is no clear common trend in stochastic behaviour of analysed discharge series. On the other hand it seems that for some small Czech rivers the on-going climate change may affect distribution of discharge during a calendar year. Our analysis also shows that all sites and river profiles in Czech Republic have to be analysed separately as a general scenario does not seem to exist. We hope that our small study pilot study can help for assessing reliability of constructed and prepared flood protection measures.

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TEMPERATURE HETEROGENEITY OF TRAVELLING FIRE AND ITS INFLUENCE ON COMPOSITE STEEL-CONCRETE FLOOR

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ABSTRACT

In order to follow modern trends in contemporary building architecture, which is moving off the limits of current fire design models, assumption of homogeneous temperature conditions used for structural fire analysis needs to be revised. In this paper fire dynamics of travelling fire is investigated experimentally by conducting fire test in two-storey experimental building. To evaluate the impact of travelling fire on the mechanical behaviour of a structure, the spatial and temporal evolution of the gas temperature calculated in NIST code FDS, which was validated to experimental measurements, is applied to the composite floor of dimensions 9.0 m by 9.0 m. Mechanical behaviour of the composite slab highly affected by regions of high temperatures and areas with only elevated temperatures is solved in code Vulcan. To highlight the severity of spreading fire causing non-uniform temperature conditions, which after-effects differ from traditional methods, a comparison of both methods is introduced. The calculation of mechanical behaviour of the composite floor is repeated in a series of three different thermal loading cases. Results of all cases are then compared in terms of vertical displacement and axial force in several positions of the composite floor.

KEYWORDS

structural fire design; travelling fire; fire test; non-uniform temperature conditions; CFD; structural response; composite steel-concrete floor

INTRODUCTION

In recent years, traditional design fire methods and their features of realistic description of fire have been criticised. Mainly in buildings with loss of compartmentalization the fire behaviour has been described in different manners. The consequences of larger compartments, evident in several tragic fires as in the World Trade Centre or the Windsor Tower in Madrid, show that fires tend to travel. As flames spread within the floor to consume fuel, regions with high temperatures and regions with elevated temperatures are created. In [1] several studies presenting the experimental evidence of non-uniform temperature across the floor area of a compartment can be found.

In relation to the non-uniform temperature resolution the spatial and temporal evolution of the temperature of the structural elements allowing to determine stresses and deformations within the structure need to be resolved. In order to investigate dynamics of travelling fire with subsequent revision of the effect of the thermal heterogeneities to a structural member, a full-scale

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fire test was executed in 2011 [2]. To demonstrate the influence of horizontal fire spread on the structural behaviour, a model of composite steel and concrete floor of geometrical and temperature data taken from full-scale fire test is introduced.

CURRENT STAGE

Traditional fire models

The traditional fire design methods widely used in structural fire analysis are based on an assumption of homogeneous temperature conditions in the entire floor area of a compartment. This conservative predication is the result of wide-scale used standard temperature time curve (so called ISO 834 curve) and parametric time temperature curve, design fire models recommended by EN 1991-1-2. Similarly zone models, advance fire models recommended by EN 1991-1-2, leads to homogeneous temperature conditions in horizontal layers across the entire compartment floor. Moving further, advanced design fire model of local fire can be applied in practical use. However the model describes a growth in size as a result of flame spread over the item first ignited, and it also enables to calculate temperature decrease with increasing distance from the central axe of the fire plume in horizontal plane, the flaming core does not move. It remains on the place of origin.

Besides the assumption of homogeneous temperature distribution traditional design fire models have limits in their applicability. Current development of multi-storey buildings uses a number of architecturally unconventional and modern design elements. A spacious atrium, large undivided spaces, high ceilings, connected floors, glass façades and other interesting elements are not according to [3] included in traditional design fire safety methods. A recent study [4] highlights the growing problem in the use of traditional design fire models. It was found that only 8% of the buildings, characterized by modern elements of contemporary architecture, as mentioned connected open spaces and glass façade, falls within the defined area of traditional methods.

Models of travelling fire

Observations of real fires in compartments show that fires tend to travel. It can rarely happen, all combustibles burn simultaneously throughout the whole compartment. Only a part of a floor area is usually involved in a fire. Until all combustibles are burned out, oxygen supply is depleted or fire brigade start extinguishing, flames spread from an ignition core to consume neighbouring fuel. Due to spread of fire, regions of higher and lower temperatures appear.

Recently, several models of travelling fire have been introduced. Clifton in [5] developed a model for fire in large compartments in which the assumption of uniform burning cannot be applied. The fire compartment can be divided into a number of design areas in which fully-developed burning occurs before moving to other areas.

More recently, Stern-Gottfried [6] has developed an alternative method for modelling travelling fires in large compartments. They suggest that due to localised burning, the gas temperature consists of near-field (temperature of flames, usually around 1200 °C) and far-field temperatures (temperature of hot gases layer). The far-field temperature T_{ff} varies with the distance from the fire. Its distribution can be determined with aid of computational fluid dynamics models or by hand calculation suggested in [7].

TRAVELLING FIRE SCENARIO

Experimental background

For the purpose of investigation of spreading fire, a full-scale fire test illustrated in *Fig. 2b* was carried out in the Czech Republic. A two-storey composite steel-concrete experimental structure of dimensions 10.4 m x 13.4 m x 9 m was designed. Load-bearing structure is shown in *Fig. 1* and described in detail in [2] and [8]. In the upper floor a natural fire spread was simulated by burning of wooden cribs placed closely together on area of 24 m^2. Total volume of ligneous mass used was 2.52 m^3. A thin-walled channel filled by mineral wool and penetrated by paraffin placed on the south side of the fire compartment served as a linear outbreak of burning, see *Fig. 2a*. The sufficient supply of air needed for burning was ensured by an opening of 10 m^2. The gas temperature in the fire compartment was measured by jacketed thermocouples located mainly in the direction of horizontal fire spread.

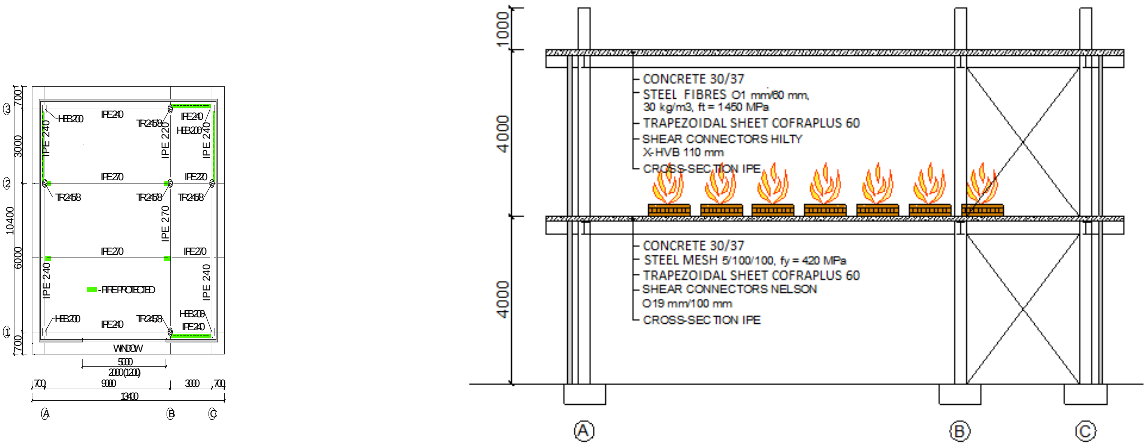


Fig. 1 Experimental two-storey structure scheme

a) b)

Fig. 2 a) Fire load scheme in the upper floor of the experimental building,

b) Photo of the fire test in the upper floor

Since the scale of experimental enclosure was not large in comparison to the scale of real buildings, high degree of temperature non-uniformity appeared. Between 26 and 30 min., when peak temperatures over 900 °C were reached, the temperature variance of the ceiling layer overgrew 250 °C. The highest degree of gas temperature non-uniformity caused by spreading of flames from the place of ignition to the opposite site of the compartment, appeared at thermocouples placed in the direction of fire spread below the beam 2. However the distance between thermocouples was not large, the difference of 400 °C, which may be observed from temperature contours in *Fig. 3*, was recorded in 15 min.

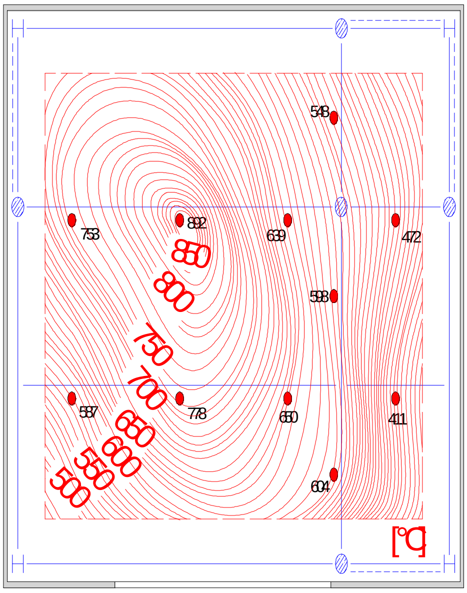
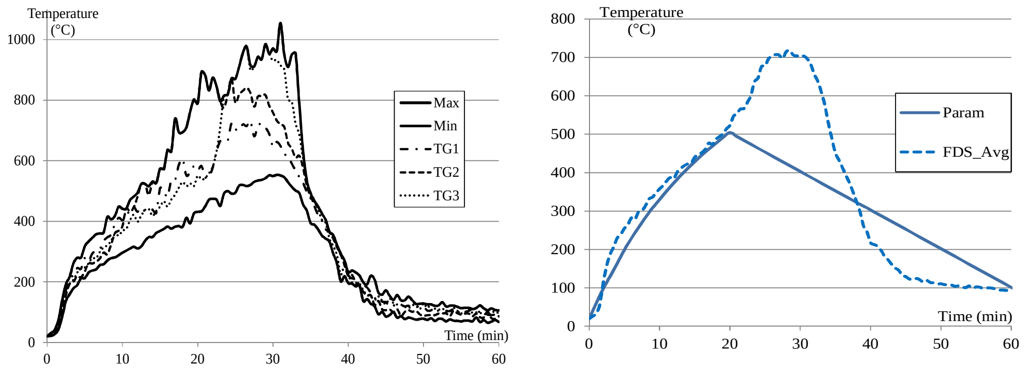


Fig. 3 Gas temperature contours (in °C) recorded in 15 min. of the fire test

Numerical simulation

The spatial and temporal development of gas temperature bellow the steel-concrete floor needed as an input of thermal loading of mechanical behaviour calculation was numerically solved in NIST code FDS 5 [9]. Gas temperature calculated in positions of thermocouples was validated by measurements carried out during the fire test. The simulation confirmed spreading phenomena from the initial outbreak of the fire to the opposite side of fire compartment. However, calculated values were slightly delayed in comparison to the measured values. The numerical model represents the tendency of the measured temperatures mainly in the growing phase, where the highest temperature gradient appeared. Despite the fore-mentioned, results of the numerical simulation are sufficiently applicable to investigate an impact of non-uniform temperature resolution on a structural behaviour. Detailed description of the numerical simulation and its validation can be found in [1].

The range of gas temperature calculated at 18 sensors bellow the composite floor limited by two curves illustrating the maximum and minimum values is shown in *Fig. 4a*. Maximum degree of gas temperature heterogeneity was reached between 20 and 30 min. on sensors below the internal beam 2 and sensors located in the corner of the compartment. Despite the distance between thermocouples being only 4 m, a significant temperature difference of 355 °C was observed in 20 min.



a) *b)*

Fig. 4 a) Calculated gas temperature during travelling fire; b) Average gas temperature from FDS calculation and parametric temperature curve.

STRUCTURAL ANALYSIS

Model of composite steel-concrete floor

The spatial-temporal evolution of gas temperature coming from FDS simulation is applied to a FEM model of the composite floor of dimensions 9.0 m by 9.0 m which represent a part of the experimental floor. The concrete slab composed of trapezoidal sheet and concrete C 30/37 is supported by 3 protected steel beams of profile IPE 240 and 2 unprotected steel beams of profile IPE 270 and IPE 220 forming its perimeter, 2 secondary unprotected steel beams of profile IPE 270 and 6 protected steel columns of profile HE200B. Steel elements are of grade S355. The concrete slab of continuous depth of 70 mm is reinforced by 2 layers of steel bars of area 196 mm^2/m placed 30 mm from the top of the cross-section. Partial interaction between concrete slab and supporting steel beams is ensured by shear connectors of diameter 19 mm of ultimate shear strength 450 N/mm^2 placed in total of 2.11 pieces/m. Data of the floor including geometry, beam cross-sections and mechanical loading employed in the calculation of structural response are illustrated in *Fig. 5*. All structural elements being loaded by respective temperature curves are divided into mesh elements of 1.0 x 1.0 m. Mechanics equations to determine stresses, internal forces and deformations are then solved by code Vulcan.

The computer program Vulcan [14] is a three-dimensional frame analysis program, which has been developed at the University of Sheffield to model the behaviour of structures under fire conditions. In this program steel-framed and composite buildings are modelled as assemblies of finite beam-column, connection and layered floor slab elements. The general continuum mechanics equations for large-displacement/rotation nonlinear analysis are applied. The main assumptions of the elements can be summarized as follows: Cross sections remain plane and undistorted under deformation and there is no slip between segments. They do not necessarily remain normal to their reference axis, as they are originally located, as displacement develops. The “small strain and large deformation” theory is adopted. This means the displacements and rotations can be arbitrarily large but strains remain small enough to obey the normal engineers’ definition. The cross section of a beam-column element is divided into a matrix of segments, each segment can then have its own material, thermal and mechanical properties, and its own temperature, at any stage of an analysis. This allows modelling of different temperature distributions across member’s cross-section and, therefore, the different thermal strains and changes of material properties that accompany different temperatures across the section can also be tracked.

To compare the impact of fire spread with uniform temperature resolution across the floor area of the fire enclosure the model of the steel and concrete composite floor is subjected to series of three different thermal loading. Thermal load in terms of uniform temperature distributed bellow the composite floor is simulated firstly by parametric temperature curve (case Param) calculated according to Eurocode 1 [10]. Geometry of the fire compartment, fire load density, ventilation and thermal characteristic of surrounding walls are considered the same as it was presented during the fire experiment. Secondly, the uniform temperature distribution bellow the floor is applied by the help of average temperate of all sensors calculated in FDS numerical simulation (case FDS_Avg). Comparison of both temperature curves of thermal loading Param and FDS_Avg is shown in *Fig. 4b*. However the growing phase of both curves corresponds well, the peak temperature of parametric temperature curve is about 200 °C lower comparing to average FDS temperature curve. With the view to investigate the influence of spreading fire scenario on the behaviour of composite steel-concrete floor 18 gas temperature developments coming from FDS calculation are applied to certain parts of the floor similarly to location of sensors in FDS model. In most cases temperature curves are applied to area of 3 x 2 mesh cells. In areas with high temperature heterogeneity - the centre of the floor and bellow the beam 2, temperature resolution is higher.

In the analysis material models of steel, concrete and reinforcement steel at elevated temperatures are referred to Eurocode 2 [11] and Eurocode 3 [12]. The temperature in the cross-section of the main elements forms a non-uniform pattern in which each major element of the section’s temperature is a proportion of the heating temperature curve. These proportions vary with time and with the particular heating curve being applied. *Fig. 6* indicates the temperature distribution in cross-sections of protected beams, unprotected beams and floor slab. All columns have temperature factor of 0.7 which is uniform across the entire cross section. Temperature patterns used in the analysis follow recommendation in benchmark study of the software in [13].

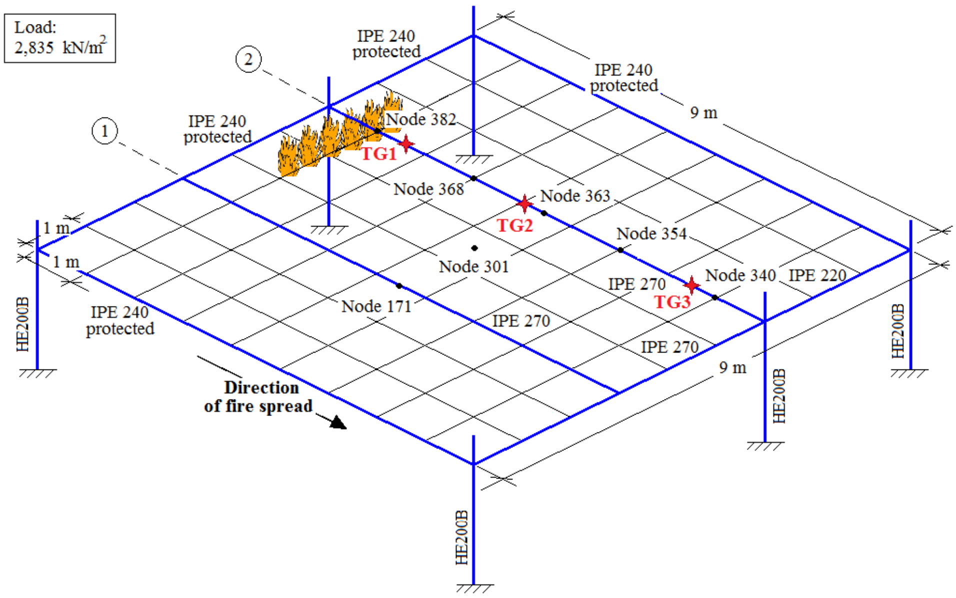


Fig. 5 Model of composite steel-concrete floor

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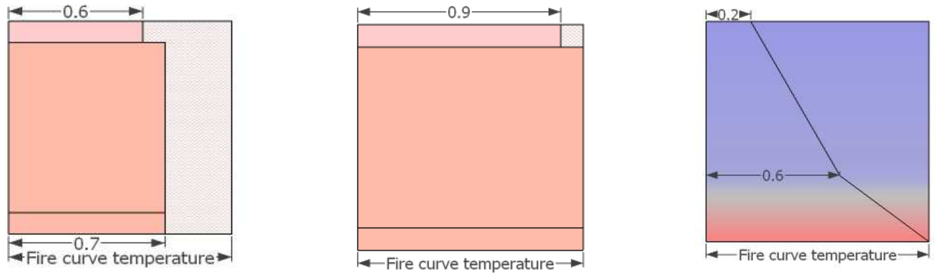


a) b) c)

Fig. 6 Temperature distribution at cross-section of: a) protected beam; b) unprotected beam; c) floor slab

Comparison of results

Mechanical behaviour of steel-concrete composite floor is investigated in terms of displacement in the central point of the floor (Node 301, for location see scheme of the model in *Fig. 5),* vertical displacement and axial force along internal beams. The essential results are summarized in *Figs. 7-9. Fig. 7a* shows the increase of deflection in central point of the floor (Node 301) for all thermal loading cases: parametric temperature and average temperature calculated from FDS results which are uniformly distributed bellow the entire area of the floor, and travelling fire temperatures coming from FDS calculation which represents natural spreading of the fire. As it can be observed from the figure deflection caused by parametric temperature increases slowly from the beginning to reach its maximum value about 150 mm in 20 min. However, both deflection curves caused by travelling fire and average FDS temperature track the previous one during first 20 min. of heating, both start to increase rapidly after 20 min. to reach their peaks in 30 min. The peak value induced by travelling fire is 360 mm, about 35 mm more than the maximum deflection caused by uniformly distributed average FDS temperature. Comparing to deflection incurred by parametric temperature curve the difference is 230 mm. The results demonstrate that the severity of fire spread when temperature of flames and only elevated temperatures act simultaneously in different locations of the floor slab causes more significant mechanical behaviour comparing to uniformly distributed temperature heating.

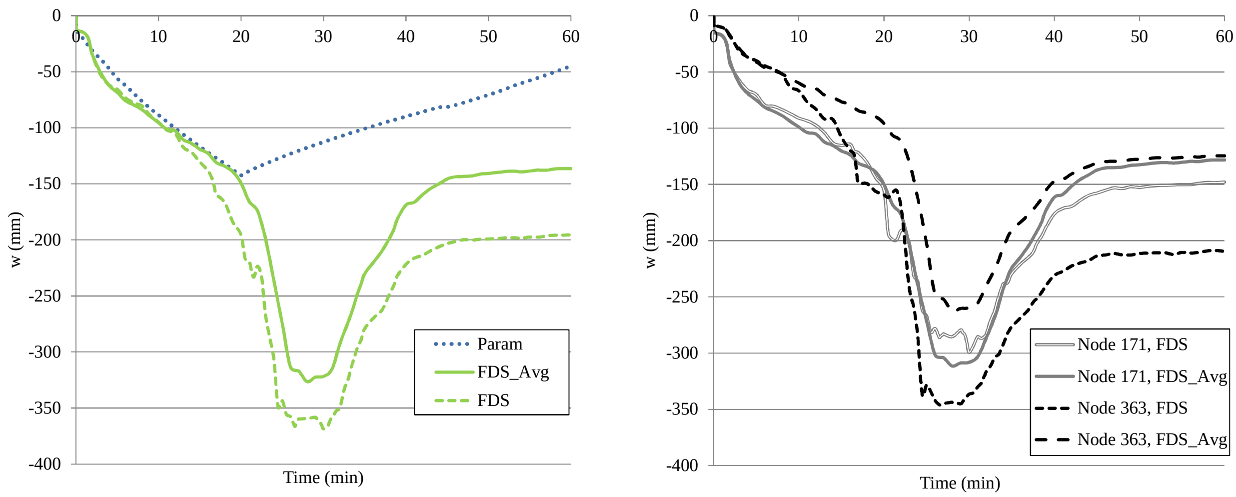
As the fire load was placed asymmetrically in the view of location of both internal beams, vertical displacement of middle point of these beams differs. In *Fig. 7b* a mid-span displacement of beam 2 is described by Node 363, Node 171 illustrates a mid-span displacement of the beam 1 (for location see scheme of the model in *Fig. 5*. The figure demonstrates the difference caused by uniformly distributed heating by FDS_Avg curve and fire spread (load case FDS). Influence of parametrical curve is no longer introduced. It can be observed that maximal displacement is reached during load case FDS at beam 2. In the same node (Node 363) the displacement caused by FDS_Avg is about 90 mm lower. Looking at beam 1, maximal displacement caused by both loading cases are about the same level, with slightly higher values induced by FDS_Avg loading. The variance of results is mainly caused by acting of flames bellow the beam 2 which high temperature is not suppressed within the use of 18 temperature curves coming from FDS, whereas the average FDS temperature is decreased involving corners elevated temperatures. It can be seen that the location of an element considered is an important factor when choosing a type of thermal loading.

Considering a recovery of displacement which occurs when the temperature is reduced, the spreading fire scenario causes the highest final residual displacements. In *Fig. 7a* it can be observed that displacement of the middle point of the slab caused by loading case FDS remains at

200 mm which is about four times higher comparing to uniform heating by parametric temperature curve. Final residual displacement of uniformly distributed FDS_Avg curve stops at 130 mm, which is about 70 mm lower comparing to FDS case. The significant difference in the final residual displacements shows the importance of covering the fire spread scenario into design fire models considered.

To investigate the mechanical behaviour of supporting steel beam 2, where the maximal effects of thermal loading are reached, vertical displacements and axial forces along its length are introduced in *Figs. 8 and 9*. Curves of vertical displacements in time shown in *Fig. 8* are described by the aid of nodes 382, 368 and 354. These nodes are located at beam 2 according to illustration in *Fig. 5*. As it can be expected according to application of temperature curves simulating the fire spread, the maximal deflection of 350 mm is reached in node 354 where the highest temperatures appeared. Vertical displacement of node 368 is about 100 mm lower and displacement of node 382 about 300 mm lower comparing to node 354. The significant difference of displacement along the beam length is caused by high degree of temperature non-uniformity bellow the beam. In contrast, during uniform temperature distribution covering both, parametric temperature and average FDS temperature curve, the maximal deformation occurs in the middle of the beam span.

In accordance to vertical displacement illustrated in *Fig. 8* axial forces in corresponding beam elements are introduced in *Fig. 9*. Beam elements used for description in *Fig. 9* are located subsequently: beam 37 lies between nodes 382 and 368, beam 35 between nodes 368 and 354 and beam 33 lies between node 354 and 340. As the loading temperature is increased compression forces start to decrease by both loading cases. Forces start to turn into tension when the maximal temperature and also deformation is reached. The final residual axial forces remains the highest by loading case of spreading fire, similarly to description of final residual displacements in previous paragraph.



a) *b)*

Fig. 7 Comparison of displacement cause by different thermal loading cases in time: a) in the central point of the floor (Node 301); b) in mid-span of beam 1 (Node 171) and beam 2 (Node 363)

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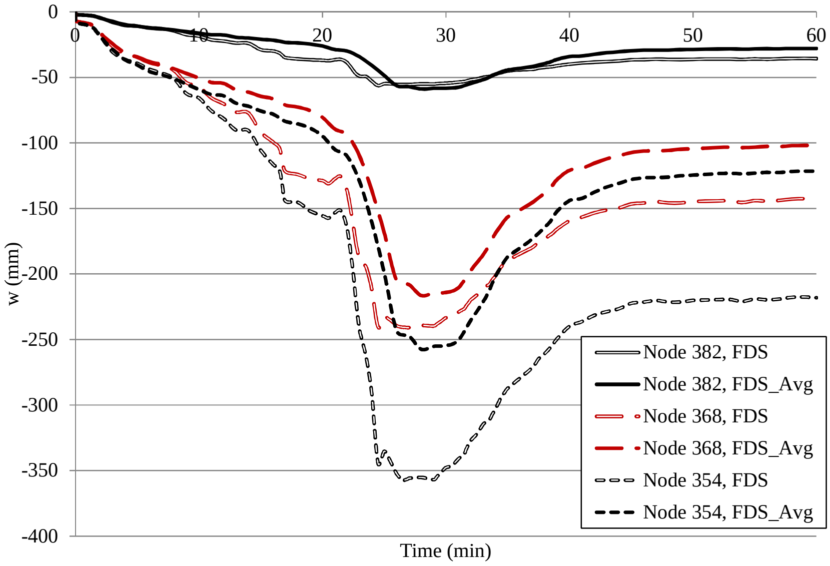

Fig. 8 Vertical displacement in several locations of beam 2

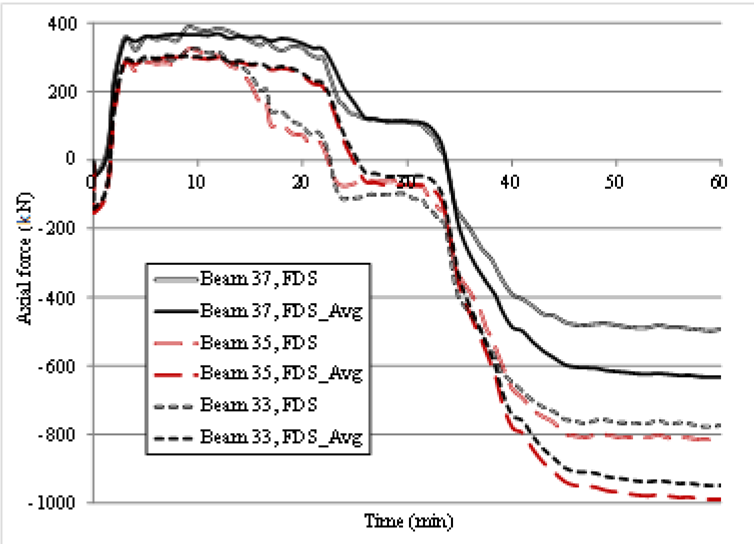

Fig. 9 Axial force along the length of beam 2

SUMMARY

In order to revisit the assumption of homogeneous temperature conditions in compartment fires used for fire design analysis, travelling fire was investigated. Based on the fire experiment executed by Wald [2], numerical simulation of fire dynamics of travelling fire scenario is performed in FDS 5. Numerical results of temperature development during the fire are validated by measurements carried out during the fire test. Since the scale of experimental enclosure was not as large as the scale of real buildings, high degree of temperature non-uniformity appeared. Variations in temperatures of the upper smoke layer up to 400 °C confirm that the homogeneous temperature assumption does not hold in compartment fires.

To demonstrate the influence of horizontal fire spread on the mechanical behaviour of three-dimensional structure subjected to more realistic temperature loading, a model of the composite steel and concrete floor of temperature data validated to full-scale fire test is investigated in this paper. To highlight the severity of travelling fire, which after-effects differ from traditional methods, the calculation of mechanical behaviour of the composite floor is repeated applying uniform gas temperature distribution in the entire compartment and compared to the effects of travelling fire. The introduced results demonstrate that regions with high temperatures and areas with elevated temperatures which act during travelling fire cause more severe mechanical behaviour of the composite steel-concrete floor. In given case the central-point deflection was 11 % higher comparing to average FDS temperature and 157 % higher comparing to effect of parametric temperature curve.

By the results described in the paper authors would like to show that a methodology allowing to describe the temperature environment in an enclosure more realistic is crucial for examination of structural response to fire.

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DETERMINING FACTORS IN THE CONVERSION OF POWER STATIONS. THE CASE STUDY OF NORDKRAFT POWER PLANT (AALBORG) IN COMPARISON TO OTHER PLANTS AROUND THE WORLD

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ABSTRACT

Due to the processes of deindustrialization and urban regeneration, former industrial buildings, especially former power plants, have been converted to new, often cultural purposes. Specifically, this paper addresses the conversion of power plants, which is considered to be a very important topic, as hundreds of decaying, non-functional power plants can be found throughout the world. It is important to rescue some and, by converting them, give them a new touch and a new use.

This paper strives to discuss the most important factors that affect the conversion of power plants aimed at finding new functions for these former industrial buildings.

Firstly, the article describes the power plants in Aalborg, and Nordkraft in particular. It deals with the complex history of the building which, due to the increasing consumption of electricity, had to be extended several times. Secondly, the paper also addresses the issues of finding a use for such large buildings and preventing their decay before the investor finds a suitable function for them. Thirdly, the paper deals with the reconstruction of the power plant from the point of view of architectural solutions and details, organisational aspects of the conversion, approach to the immediate surroundings, and financing options. Finally, some trends and opportunities for the reconstruction of similar buildings around the world are outlined in order to show the options for saving them by means of conversion.

KEYWORDS

Nordkraft, Industrial heritage, Power station, Conversion, Aalborg

INTRODUCTION

Coal-fired power plants have been abandoned due to their outdated technology, poor condition of the buildings and, most importantly, massive production of smog in the city centres. After losing their original purpose, they often found different temporary uses, with minor architectural interventions. The interest in the conversion of power plants began in the early 1990s. They are single-purpose buildings which require different uses and diverse architectural solutions but, nevertheless, have been frequently rebuilt. All of these interventions depend on the history of the buildings, the buildings themselves (material, character, condition of the original buildings, heritage protection), the location and its transformation, funding and new uses.

In this article the aim is to find key factors in the rebuilding of power plants, with the case of Nordkraft as the focal point. The article is written from the perspective of a foreign architect dealing with industrial heritage, its preservation and conversion. Therefore, the focus of the article is to describe the entire local and historical context. Thus, focusing both on the architectural design and the material solutions of the power plant. Their age and period of construction need to be taken into consideration. Another key factor could be the length of time for which they were not used and were empty, as well as the condition in which they have been preserved. An integral part is the area where the buildings are located, and the development of their surroundings. We cannot forget the economic and social conditions that dominate in the vicinity of the building. We should not neglect the new purpose, but also the original purpose (electricity for residents, hospitals, factories, mines and public transport). I look at Nordkraft as a point in the structure of the city without discussing its urban function. Neither do I address the exact technological equipment of the plant during its operation.

I have defined several key factors that I further examine in all of the selected buildings. The aim is to determine the factors that are crucial for the conversion of power stations. On the other hand, I identify factors that do not affect the conversion. For this article I have used the method of exploring the various stages of the Nordkraft power plant, from its construction to its conversion. The same method has been used to look at the architectural solution of the conversion of the building, especially of the interior and the surroundings. The method of comparison has been used to identify the trends and key factors. For greater clarity, an illustrative table has been added.

DEVELOPMENT OF POWER PLANTS

Public power plants began to emerge as electrical lighting and other electrical appliances found their place in private homes and small businesses, as well as factories and public institutions. Before long, electricity became a part of everyday life. At that time, a large number of coal-fired power stations were built, most often on the banks of rivers, lakes and fjords. The technology in these buildings was often modernized, but today most of them do not serve their original purpose. Some of them were fortunate enough to be rebuilt to a new use. Some former plants still need to find new opportunities to be used and saved for future generations. The best form of saving industrial buildings is to find them suitable contents, either in the form of museums or converted buildings.

DETAILED ANALYSIS OF NORDKRAFT POWER PLANT IN AALBORG

Aalborg is a medium-sized city located on the banks of the Limfjord, North Jutland, Denmark. It has about 200,000 inhabitants (2010) and, for many years, the place for large-scale industry for cement, distillery and shipbuilding occupied the waterfront on both sides [1]. Aalborg is a good example of a city where transformation from an industrial city into a cultural city is ongoing. Especially in the city centre, the transformation of the former industrial areas into culture related facilities, office space or housing estates is in progress. . The harbour at the waterfront has been turned into public buildings, which include university buildings, the House of Music and restaurants. With the construction of the House of Music in 2000, the conversion of the central waterfront started. This is where the power plant, the slaughterhouse and other historic buildings are situated [2].

Characteristic of Nordkraft

Nordkraft is a former coal power station transformed into a cultural hub. Today we can only see parts of the former power plant. The larger part of the building houses a cultural centre and is open to visitors. This section of the power plant was built between 1942 and 1980. Because of the long construction time the building is characterized by a mixture of different architectural styles [3].

The centre has a size of approximately 30 000 m^2 [4], therefore it offers enough space for various facilities. For example inside the building there are a cinema, restaurants, a fitness centre and other facilities. Nordkraft is located at the central harbour front (behind the House of Music) in Aalborg (*Fig. 1.*). Originally, it was located on the borderline among the city, the harbour and the industrial zone and was built to supply the industrial sector, as well as the city itself with hot water and electricity. Next to Nordkraft, and on the other side of the harbour, was located the former Tivoli (Karolinelund), now a public park. Therefore, this place has the potential to connect these different places, different groups of people, and different activities.

Fig. 1: Local plan of Aalborg; Legend: ***1.*** *Nordkraft,* ***2.*** *The central Harbour Front - transformation 2006-14,* ***3.*** *Østre Havn - transformation 2013-15,* ***4.*** *House of Music – construction 2010-2013*

Lighthouse

Using the term of urban scholar Gitte Marling Aalborg Nordkraft could be defined as a kind of a lighthouse. In this context, the expression "lighthouse" is a metaphor, not a real lighthouse on the coast. In order to understand the authors' intention it is necessary to read the definition of a lighthouse by Marling, The City Experience

"We label projects "lighthouse" if the project contains a cluster of programmes localized within a relatively confined area in the city. These are expressions of a public strategic intervention and they are related to large investments. Lighthouse stirs large local attention and often has a massive local backing. They function as motors for existing activities and generate new cultural products and activities." [5] Nordkraft as a "Lighthouse"

Based on that definition, Nordkraft as a lighthouse matches various criteria, such as:

- identity of the city, nearly the only remnant from the days when Aalborg was a significant industrial city;

- cultural dynamo for the whole region, serving the residents and also the people in the nearest neighbourhood in the region, and tourists in Aalborg; the tourist information centre;
- place for various cultural events for different groups of people;
- prominent landmark, well apparent in the cityscape.

History of Power Plants in Aalborg

Three thermal power plants were built in the history of Aalborg and its surroundings. Their status changed with the changing needs of the population, the industry and the protection of the environment. The oldest plant is located in the very centre of Aalborg, producing direct current, unlike the other two. The second plant, Nordkraft, was situated on the outskirts of the city next to the industrial zone and on the harbour front. The third power plant, still functional, which has been producing energy since 1977, is located on the other side of the Limfjord and far outside the city. This section outlines a brief history of the oldest power plants, followed by a more detailed description of Nordkraft and its transformations.

The light station

The first power plant (1895-1909) in Aalborg, in Doktorens Gyde, was private. “The light station”, as the station is popularly called, was originally only for 54 clients [3], most of them lived in its vicinity. [6] The central location in the city centre became impractical due to the supplies of coal. This power station produced direct current, which was subsequently exchanged for alternating current. That was another reason for the creation of a new power plant. (*Fig. 2.*)

Fig 2. Local plan of power plants in Aalborg; Yellow - The light station; Blue - Nordkraft

In 1889 the old brick factory was demolished and replaced by a newly planned power plant built in 1909 [3]. This power plant was built close to the Limfjord, due to the transportation of coal. It was easy to access via the inner harbour and it was outside the city. The rearmost part of the inner harbour was shortened. In this place was created a new coal store for the new plant. It was necessary to rebuild the harbour only for shipping industrial raw materials for power plants and small fishing boats, which were there before, were not allowed any more. Today, due to the urban growth, the area is located in the centre of Aalborg and the harbour-related activities are moved further to the east and to the periphery of the city.

Nordkraft – Power Plant

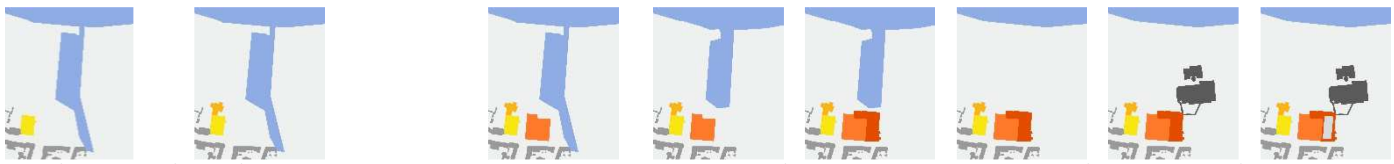
Nordkraft was designed by many architects and engineers. Therefore, the construction was divided into several stages. In 1909 Architect J. Jørsensen designed the oldest part of the power plant with the red brick style romanticism and national features. The elements are made of bricks in light colours and they harmonize with the window frames. The selection of the material and the proportions are based on their surroundings and the historic city centre. The machine room has also large arched windows. In addition to it, the industrial building was decorated with frescoes which are exactly related to electricity. [3] In 1916 there was another extension of the building. The engine room, the boiler rooms and new chimneys were built. The engine room was decorated with new frescos of mermaids; one of them has a hand sign of the city of Aalborg. The building was completed in 1919. In the 1930s the city acquired a new building plot next to the existing power plant. The new site eastwards of the power plant was necessary to be created because of the increasing consumption of electricity [3].

The new larger boiler room “1” and the turbine hall were built eastwards from the engine room, across the street, in 1942. The construction was only finished in 1954 due to the rationing of steel, needed for reinforcement, during World War II. At this point, the plant was also equipped with technology to supply hot water for the city of Aalborg. [3] In the boiler room four boilers were installed, three boilers at the end of the 1940s and the last one at the beginning of 1950s. [7] The architectural model for that part of the plant was the Spritfabrikkerne distillery, also placed in Aalborg [3]. Therefore, the building is built of red bricks, has industrial windows that visually support the height of the building. A concrete frame system with three coal containers is hidden behind them. Between 1954 and 1956 the inner harbour had to be vanished due to the planned expansion of the power plant. It was necessary to build a new coal depot. [8]

the oldest engine room with frescos (1909) [3,11] | the original inner harbour, at the back power plant (around 1942)[12] | shortened and rebuilt inner harbour (around 1954) [12] | construction of youngest part (1970–73) [8] | aerial view of complex of buildings (1980) [3,11]

1900 1950 1990

1909– around 1914 | 1916-19 | 1942-1954 | 1954-56 | 1956-62 | 1962 | 1970-73 | around 1980



The first part of construction 1909 – around 14 | the first extension of the power station 1916-19 | outbuilding new boiler hall "1" 1924- 54 | shortening of the inner harbour 1954-56 | extension boiler room "2" 1956-62 | the removal of the inner harbour 1962 | extension of the youngest part 1970-73 | modernization of technology around 1980

In the summer of 1956 the new boiler room “2” with turbines was built. First three boilers were ready for use after two years, and the rest, with 72 MW turbines, were put into operation in 1962. This part has a distinctive checked pattern façade, formed by white plaster and windows. The façade hides a concrete bearing structure, once again accompanied by concrete containers. During this period new chimneys were built for that section, which dominated the city skyline for nearly 40 years. [3] The next expansion, between 1958 and 1959, was a new large oil tank [7].

In 1970 the plant was extended for the last time by architect Arne Kjær Tegnestue. The inner harbour had to be completely abolished. It was situated north of the oldest part of the power station. The extension site was across the road and bridges were used to connect it with the older buildings. That section, with a production capacity of 269 MW [9], was officially opened on 10 May

1973. It was built of monolithic concrete and clad with trapezoidal sheets, which was typical for industrial buildings at that time. Also it was the tallest chimney in the city [3].

In the 1980s the façade of boiler room “2” was completed from outside with a reinforcing steel structure, on the grounds of new and better technologies for coal processing [10]. The production of electricity and hot water in Nordkraft ended in 1990 [3].

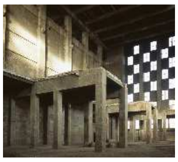
Nordkraft – the Cultural Centre

The transition of Nordkraft from a power plant into a new cultural lighthouse was not easy. Nordkraft barely escaped total demolition. Nordkraft was indeed rescued by the decision that it would be a shame to demolish the building, but the new purpose it should serve was not clear.

Nordkraft was out of use for 16 years, from 1990. At that time it just stood there empty, unused, and was going to be slowly devastated and partially demolished. The dilapidated and dirty complex with boarded-up windows threw a bad light on the city and its skyline. This created an extensive area of bad land/wasteland on the shore. The area looked chaotic, lacking a typical urban structure. It was composed of paths, rails and the coal store. In 1999 a plan for reusing one of the oldest parts of the plant as the "Techno Vision" Technical Museum was drafted, but the proposal was not successful, mainly because of financial difficulties [2].

The youngest part of Nordkraft with the city’s highest chimney was removed between 2000 and 2001. At the same time, a general debate about the use and protection of Nordkraft took place and, as a result, the demolition works were stopped in early 2002 [3]. In 2003 plans for preservation and conversion of Nordkraft were signed by the city. One year later, the City of Aalborg bought Nordkraft from the company Elsam A/S. At the time of the purchase, only the oldest part, in a devastated condition and without the chimney and technology, was standing. The


original position of the road and condition of the building


empty building without technology


original state before conversion (2004)


after conversion of the repaired façade, new parterre (2012)


House of Music, before Nordkraft (2014)(COOP HIMMELB(L)AU , Cubo)

1990 2000 2010 2015

Demolition until 2002

Conversion 2006 - 2012


demolition of the youngest part until 2002


condition in the purchase in 2004


conversion into a cultural centre 2006-2012


construction of House of Music 2010-2013


continued construction on waterfront 2010-15

proposal to place the monument under heritage protection was unrealistic from the beginning. At that time it was not usual to declare an old industrial building a heritage site.

Afterwards, in 2005, an architectural competition for the conversion of the power plant was announced. [2] The competition was won by the architectural firm Cubo Architects in January 2006. Their concept of preserving the original structures was unique because of their understanding of the needs of the stakeholders, for whom they sought to find the right place in the building. Their philosophy was characterized by love and simultaneously empathy to form the different areas and connect various levels of intervention in the original structure. The result was pure, raw and functional architecture. In the same year, the city introduced a comprehensive plan for the central harbour, with parks, the Utzon centre and a promenade [2]. According to the plan Nordkraft was supposed to be surrounded by a green space [14].

The conversion of the power plant was divided into three phases. The transformation of the square in front of Nordkraft was part of the first phase and was completed in 2009. The second phase, the boiler room and turbine hall, was completed in 2010 and was officially opened a year later on 10 October. In 2012 the eastern connection between Nordkraft and Teglgards Plads was built, making it possible to walk through the building. [2] The architectural office was awarded the 2013 Renovation Price for the conversion of Nordkraft [16].

The oldest part of the power plant (1909-1919) was not included in the conversion, because it still served as a heat exchange station. Another part of the building was converted into an office space [16]. In March 2014 the House of Music was opened near Nordkraft. In 2015, once the Østre Havn eastwards of Nordkraft is finished, the transformation of the waterfront in Aalborg will come to an end. The new area with the new buildings is described as a small Manhattan in the planning documents [2]. Nordkraft itself is a project that won't be finished in the near future because the transformation will continue bringing the need for minor changes and adjustments.

Specific Features of the Conversion of Nordkraft

With point of departure in the historical development of Nordkraft, I turn to the conversion of the power plant from different perspectives. I focus on the architectural solutions and the interiors of the building itself, as well as on the surrounding public space. All this is set in the context of the economic and political situation and support from the city of Aalborg. Nordkraft could be described as a single-purpose building. Thus, finding a new use is more difficult than in a multi-purpose building such as a textile factory or a warehouse. The power plant has big halls to provide enough space for the necessary turbines and other technology. Today, it is a challenge to find a suitable follow-up usage for such a large space. Moreover, it is necessary to preserve some parts of the old power plant in order to show the original purpose of the building.

Economic and Political Background of the Project

This project is special because of its long transformation process (from 1996 until today and even further).

Political and Public Debate

Throughout the public debate about the preservation of Nordkraft, two decisions were made to preserve the building. Regarding to the first decision, the City of Aalborg had to decide whether to preserve Nordkraft as a formative building for the city skyline or to demolish the building. In the end, the city decided not to demolish the old power plant, because the building was already an inherent part of the skyline.

The second major decision, inspired by the history of Emscher Park, was crucial. The park in Germany is a good example of old industrial properties which are open to the public today. In industrial areas, the reuse of old industrial buildings can give rise to a new phenomenon. We can visit such places, we can see old buildings used in a new way, and cleaner nature and surroundings. In this new area a new identity for the inhabitants and the city has been created. The idea behind the preservation of Nordkraft was to create something similar to Emscher Park. For this park, the initial idea came from the government, the surrounding cities, and not from private institutions. The same was necessary for Nordkraft, only on a much smaller scale.

Public Presentation of the Project

The **3T** method - talent, technology and tolerance of conservation of the power plants was used for the project. The presentation of the project was public and, therefore, open to everybody. For example, politicians, citizens and planners had access to planning documents, metaphors, sketches and other relevant plans [2].

Economic issues

Nordkraft was planned during the economic boom, around the year 2002. This project played a key role in Aalborg’s transformation into a cultural city. The Municipality, as the main investor, was economically responsible for the whole project. The renovation and conversion of the older industrial building involved the highest financial risk. At the time of the crisis it was necessary to replace a company gone bankrupt with government and municipal institutions. Economic worries persist until today, even when the University uses some rooms in Nordkraft and pays rent [2].

Architectural Design

This conversion is primarily about a substantial change of the function, not so much about architectural intervention. There has been no significant change in the appearance of the building; no new expressive forms have been added which could make the building more pronounced or give it another dimension. The main interventions were made inside, connected with the reuse of the building. Three new floors were installed in one part.

Historic Façades

The façades were cleaned up, but they still look original. The windows were repaired without changing the proportions or the material. [2] Subsequently, exterior lighting was installed in order to enhance the character of the building at night. The same approach was adopted with the historic façade of the protected building where a coal conveyor belt was preserved on the south façade. The façades were equipped with factory clocks to emphasize the atmosphere.

The Interior

The conversion could be characterized as a "room in a room", using boxes – elements placed in unheated free space. Inside the building we can see the contrast of new and old material, both in texture, colour, scale and processing of the details. The architects mainly retained the scale in the entrance hall, where you can still feel the original raw structure, the monumental and open space. This preserved space is therefore the most impressive room in the whole building. Moreover, the concrete tanks are still there, with cafés and restaurants beneath them.

Another element used in the interior is a three-floor box suspended in boiler room “2”. This allows a better use of enormous height of the room, and supports the contrast between the new boxing and the raw concrete tanks. Some elements have been retained as reminders of the original function, such as the crane, indicators, and others. Due to the diverse and original architecture the space may seem slightly chaotic. Nevertheless, the feeling of raw architecture and the mixture of old and new material creates a unique atmosphere and light in this new centre of Aalborg.

Activities

One of the main purposes of Nordkraft is to provide space for activities, office space and public space where people can meet in groups and have enough room for various activities. Nordkraft hosts a lot of activities linked with Aalborg, but also with its surroundings. It offers a broad range of cultural opportunities for the entire region of northern Jutland as its main cultural centre and a living city organism. It is supposed to be a place for exchanging views between different social groups [5].

Actors

Nordkraft houses 25 facilities such as restaurants, music and sports facilities, theatres, an art school and an exhibition space, a music school, a university, a youth club, a cinema and education centres and offices related to culture and sport [4]. It is a mixture of features which are not easy to coordinate, but if it works, Nordkraft will never be empty. With a variety of interests, the house can be used by a wide range of age groups, from sporting children, young people and older people who go to the health centre. Underground rooms are suitable for clubs, cinemas, and theatres, while the upper floors, with enough daylight, are used as office space [2].

Municipal Cultural Centre

Nordkraft as a municipal cultural centre offers, especially in the boiler hall, enough space for markets, performances, shows, concerts, lectures and workshops. Therefore, Nordkraft forms an efficient and inspiring neighbourhood.

Surrounding Public Space

The surroundings of Nordkraft are densely built-up, due to the lucrative location in the centre of the city. In the process of transforming the central waterfront the planners and architects were always concerned with the whole area and paid attention to the development of the whole area.

Parterre

A part of the conversion was to solve the problem with traffic. A busy road was suitably moved towards the east, and thus created a public space between the original buildings of the plant. The selection of materials corresponds with the interior solution: corten and concrete. The difference in elevation between the street and the entrance was solved by using concrete ramps and stairs. There we find benches, bike racks and a couple of trees. [2] Unfortunately there is no industrial imprint and no industrial atmosphere like inside. This space is open to every road user. The main reason is the car park in the yard of the oldest part of the power plant. With the opening of the parking lot under the House of Music, the park may be closed. The traffic then would be very limited, with only a few cars entering the yard when absolutely necessary.

Parking Solutions

As with every conversion, parking is very challenging. It is almost impossible to build an underground parking lot, as is the case of Nordkraft. The solution is to create parking spaces around the building. It is therefore advantageous for the city authorities to oversee the transformation of the whole area, as this makes it possible to find a comprehensive parking solution for the whole area. This is also the case of Nordkraft in Aalborg where you can park in the vicinity, under the House of Music and other places.

Interconnection of Cultural Institutions

The original Nordkraft was in contact with the fjord, (the Limfjord). This contact has not been preserved but, at least, an interesting waterfront could be created, serving for people, and attractive buildings could be built. A big drawback I see in Nordkraft is that it is not linked with the House of Music. There are ordinary road crossings, but since there is a large underground parking under the House of Music and both buildings have a rich cultural life, there should be a suitable interconnection between these cultural institutions to support their cooperation.

Solution of Greenery Around

Greenery is an important element in the conversion of buildings; therefore, we should keep it in mind and make use of it. It helps us to understand the scale of the building, because its size is well known to us. At the same time we create a green space for relaxation in dense urban areas. In Nordkraft we can see an effort to have greenery in the immediate surroundings of the building. Such surfaces are suitable for small industrial footprints such as overgrown rails, wagons, parts of cranes and others. Nordkraft aims at distributing a diverse cultural atmosphere throughout the city of Aalborg and the region of Northern Jutland, much like hot water and electricity used to be distributed in the past [2].

COMPARING THE CONVERSIONS OF SELECTED POWER STATIONS

For this comparison I have chosen different conversions of power plants at different times, with different functions, methods of funding, with different locations in the city and in the world. The selection illustrates different approaches to conversion, as well as specific features of new use of former power plants. These examples were chosen from a wider portfolio of researched objects. (Tab. 1)

Brief characterization of selected power plants

The Charles H. Shaw TLC (Technology and Learning Centre), former Sears, Roebuck and Co. Power House (Chicago, the USA), was selected because of the atypical use. The conversion to a school (9 and 12 classes) and community centre is a rare case. Along with other old and new buildings, the power plant, located in an old industrial area, was transformed into a campus surrounded with public space. An important reason for conversion is the preservation of technology, machinery, and piping as an inducement for students. [18] I think the original industrial building is a fitting place for a school. Students learn to appreciate history, even though the conversion is complicated.

Another selected power plant is the ***Canberra Glassworks***, former Kingston Power House (Canberra, Australia). One of the reasons why I have chosen this museum is the need to add a new function in order to secure funding. Another reason is the fact that the conversion concept is similar to that of the Red Dot centre in Essen. Monumental spaces of the old power house are contrasted with the lightness, transparency, fragility, vivid colours and small scale of the artistic glass objects. Another reason for choosing this power station is its new chimney, which corresponds to its original form. It is made of glass and serves as a light tower for the museum. [19, 20]

At the time of its construction, ***Ottawa Street Power Station*** (Michigan, USA) was an important building built in art deco style. The building was characterized by its state-of-the-art equipment, hidden smokestacks and stunning flame-like designs on the façade. A remarkable masonry scheme symbolizes the combustion of coal. Thus, the plant is both a monumental sculpture and a fluid painting in masonry. Huge stacked-design windows echoed the building’s silhouette, further tightening the unity of form. Many smaller details are added to the design, among them a huge set of burnished metal doors emblazoned with Oz-like lightning bolts. [21] It has retained a few details and structural elements, but has lost its original appearance, including the patina and the colours. But this is a typical example of a power plant converted to an office space, its potential lying in its central location and in the character of the building itself (many floors with universal appearance of the interior, and space that is easy to change).

Tab. 1 Comparing the Conversions of Selected Power Stations

Name	**Nordkraft** [2,3]	**The Ch. H. Shaw TLC** [18]	**Canberra Glassworks** [19,20]	**Ottawa Street Power Station** [21]	**Tate Modern** [22]
history					
construction	1909-1973	1905 - 1906	1913-1915	1937 -1946	1953-1963
source	coal, oil	coal	coal	coal	coal
termination	1990	1973	1957	1992	1980
without the use	16	34	**48**	**15**	17
conversion	2006 - 2011	2007 - 2009	2005 - 2007	2007 - 2011	1997 - 2000
architecture					
material	red brick	red brick	concrete building	multicolour brick	red brick
	big steel factory windows				
characteristic	collage of buildings	slightly decorated	interpretation of classical architecture	art deco	axially symmetric expression
	modern style of industrial architecture				
building location	itself new district around	old industrial area new district around	old industrial area new district around	itself new district around	itself small interventions
immediate surroundings	new public area	new campus	cultural area	public "linear" park	public park
regeneration	harbour	old industrial area	old industrial area	old industrial area	small quarter
transformation	new building	new building	surrounding public space	new building	surrounding public space
supply	ship	rail	rail	ship	ship
conversion	inside intervention, minimal outside (entry, arrival and staircase)				
heritage protection	No	Yes	Yes	Yes	No
smokestack (now)	0	1	1	0	1
founds	public private partnership	The Homan Square community	artsACT	The Christman Company	Tate Gallery
activities	25 actors cultural, sports **mix used**	school assemblies, community events **education**	glass art production and workshops **cultural events**	office space **office**	Tate Modern with café and shop **cultural events**

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The oldest reconstruction I have chosen is the ***Tate Modern***, former Bankside Power Station (London, United Kingdom). As a power station it was an icon in the 20^{th} century: a monumental building with a modern, symmetrical façade. As an exhibition space it has become an icon of conversion. A concept of the conversion is very similar to Nordkraft, especially the minimum interference with the exterior and the empty space in the interior. With its preserved chimney Tate Modern is a landmark in the city's skyline. [22]

Results of Comparing the Reuses of Different Power Stations

In this part of the article I mention the results of my research and comparison with Nordkraft, following the same structure as in the table.

History

Large power plants were built in the 19th and 20th century, mainly in the early 20th century. All around the world, the overwhelming majority of these plants are coal-fired, some exceptions are gas-fired. The first public power plant, which was gas-fired, was built in the USA by T. A. Edison and G. Westinghouse. As a consequence, large power plants were built earlier in the U.S.A. than in the rest of the world.

Architecture

Most of these buildings are examples of modern industrial style. There is not much diversity among countries in the same period. Boiler rooms make the buildings clearly legible within the urban environment. A boiler room is the heart of the plant, characterized by extremely high industrial steel-framed windows. A chimney (or chimneys) is also a typical feature. Another common feature is a brick retention wall, even in areas where such structural elements are not quite typical.

Nordkraft, with its red brick and large steel-framed factory windows can be classified as a typical plant built before the World War II.

Building Location

Power plants were often built outside cities, either close to water or with a connection to the railway because of the need for coal supply. As cities grew, the plants became part of them and today they are often situated in the centre. Plants built in areas with heavy industry are an exception. You can find just workers' colony, not a functional city in their surroundings. Urban power plants were surrounded by other manufacturing buildings that had lost their meaning, and thus these areas are significantly transformed. Power plants in such places can serve as drivers of new construction, as well as remnants from history. After regeneration the coal store, which occupied a large area near the river, is either transformed into a park (such as the Tate Modern), or new buildings are constructed there (such as Nordkraft, where the House of Music was built. Nordkraft became attractive for its location, like most power plants, which were built for cities and their residents, for the light industry and for transport (trams, suburban trains, underground).

Conversion of power plants does not differ significantly across the world. Similar methods of work are used. Most interventions are made in the interior, little is changed outside. To my mind, for a conversion to be successful, it is important to maintain the rawness of the architecture and to use materials which differ from the original and characterize the present time. Often, there is no need to add new features, since the original structures are already complicated enough. An important point is to maintain the scale of the building and the interior. This primarily applies to the boiler hall, which should be preserved in its full size. Nordkraft is a suitable example of such approach.

Heritage Protection

Nordkraft and the Tate Modern are examples of buildings without heritage protection. There was a major investor determined to preserve the genius loci. Heritage protection makes it more difficult to find an investor and, therefore, the buildings decay, like the Canberra power plant.

Smokestack

It is difficult to find any purpose for the chimney; therefore, many of them have been pulled down. The plant thus loses one of its typical signs and it becomes difficult to tell its original purpose. Chimneys have an impact on the skyline, and bringing them down can help, but also cause damage. Is the smokestack the “leitmotif” for the power station? Nordkraft lost its chimney very early, but there is a chance a new chimney will be built, like in Canberra Glassworks. It is a modern concept of the same size and in the same place as the original smokestack.

Funds and Activities

Funding is closely linked with the use. Financing of power plant conversion is significantly influenced by the economic situation. In times of economic boom it is not a problem to find funding for a single-purpose building. This can be seen at the Tate Modern: a typical example of cultural use during economic boom, now pretty much infeasible. The more recent conversion of the Canberra plant had to accommodate workshops in order for the project to be viable. Recently converted buildings are mostly used as office buildings, which are easy to adapt so that they can be rented out and ensure profitability. A number of recent conversions opt for mixed use (sport, relaxation, school, restaurants, clubs, etc.). Nordkraft is a typical example of mixed use. In order to carry out the project, cooperation with a private investor (DGI) was established. In the USA it is possible to draw on subsidies to fund the conversion of power plants.

Influence of Individual Factors

We can find little difference between the character of coal-fired power plants built between the wars and just after the Second World War. This architecture is characterized by red brick, with high windows in large industrial buildings that are part of extensive complexes. The spacious interiors of these buildings give rise to specific requirements for the new use. The dimensions of the rooms give them a specific atmosphere which can be enhanced by the conversion. The age of the power plant, therefore, is not a significant factor. On the other hand, the condition of the building is a key factor. The length of time for which the building is not used does not have such a great impact as its condition, even though those two factors are very closely related.

Another important factor is the location of the building: a number of power plants located outside the city were demolished, such as the Stella Power Station in Newburn, UK. A very important factor is the use of the immediate surroundings, which can aid in financing the reconstruction due to new construction, as we can see at the Battersea Power Station in London. The location of the power plant at the waterfront is often taken advantage of, as the waterfront is often cited as the most lucrative place in the city. The method of conversion is not essential and often does not differ in character from the others. Heritage protection or the numbers of chimneys do not play a role in the conversion. The most determining factor is finding the right investor who has a vision for a suitable use, as we can see in most conversions of all types of industrial buildings.

CONCLUSION

The feasibility of conversion is a factor that is composed of the original state of the building, the location, the new use and the possibility to use the surrounding space of the plant. We should not forget that even after conversion the genius loci and the identity of the place can be preserved. These factors include economic aspects (financial requirements of the conversion and new use, the use of the immediate surroundings and accessibility), architectural aspects (especially if this building could become an icon for the city and an important architectural component which has a piece of history in it, creating an atmosphere that fascinates people) and historical aspects that are closely related to the architecture, the site and the owners. There is also the factor of the city's attitude towards the building and the willingness to support its preservation. Nordkraft satisfies all the requirements and has therefore been retained and converted into a cultural lighthouse.

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