SPSUACE
1832

ARCHITECTURE & ENGINEERING

Volume 3
Issue 3
September, 2018

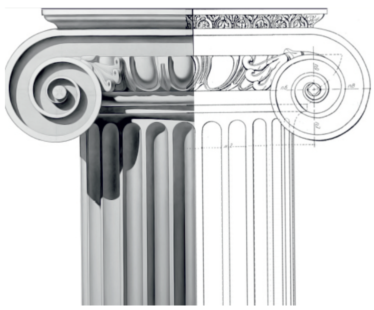
By Architects. For Architects.
By Engineers. For Engineers.

Architecture
Civil and Structural Engineering
Mechanics of Materials
Building and Construction
Business and Management in Construction
Urban Planning and Development
Transportation Issues in Construction
Geotechnical Engineering and Engineering Geology
Designing, Operation and Service
of Construction Cite Engines

eISSN: 2500-0055

Architecture and Engineering

Volume 3 Issue 3



CONTENTS

DOI: 10.23968/2500-0055-2018-3-3-3-9

FORMATION OF A FUNCTION SERIES FOR ESTIMATES OF TRANSPORTATION ENERGY EFFICIENCY BASED ON BARTINI'S LT-TABLE ENTITIES

Jurij Kotikov

Saint Petersburg State University of Architecture and Civil Engineering
2-ya Krasnoarmeiskaya st., 4, St. Petersburg, Russia

cotikov@mail.ru

Abstract

A function series for estimates of transportation energy efficiency is formed based on Bartini's LT-table entities. The study represents a follow-up of the method provided by the author to estimate transportation energy efficiency based on the Bartini's L6T-4 entity. The Bartini's LT-table, supplemented by Aleinikov, is adjusted using system representation of the energy series of entities: Energy–Linergy–Arergy–Volergy. Methodical specifics of obtaining transportation energy efficiency estimates for 1D, 2D and 3D spatial objects are considered. A numerical analysis of transportation in a 2D zone is carried out following a hypothetical example of daily commuting in the Saint Petersburg agglomeration.

Keywords

LT-systematization, Bartini's L^mT^{-4} entities, Energy, Linergy, Arergy, Volergy, megacity, agglomeration.

Introduction

Estimation of transportation and logistics energy intensity is a topical issue (Kotikov, 2006). The issue is becoming more relevant with an increase in movement speed, transportation scale, coverage, as well as with development of new types of vehicles, power plants and fuel (Kotikov, 2006).

Logistics made the way from one-off deliveries to supply chains (4PL) and reached the level of network deliveries (5PL). At this development stage, one of the possible ways of subsequent methodological improvement of the logistics apparatus is mastering methods of transfer from network models to field models. Another way, in the light of developing space and air (Kotikov, 2018; Leonov, 2010) transport, three-dimensional distribution logistics (high-rise warehouse terminals, office and residential skyscrapers, etc.), is development of the optimization modeling of three-dimensional networks and fields.

The listed aspects require to develop methods to estimate energy efficiency of engineering systems in terms of the requirements of the future technological paradigm. In his previous papers, the author of the article used the Bartini's LT-table L6T-4 entity to develop new methods for energy efficiency estimation (Kotikov, 2006, 2017a, 2017b, 2017c). The applicability of the method based on this entity to estimate linear deliveries of cargo was shown.

In this study, a task of developing criteria and techniques for 2D and 3D options of distribution logistics based on Bartini's LT-table entities and constructing a function series with dimensionalities ranging from 1D to 3D is set.

The author's adjustment of several concepts and terms introduced by his predecessors based on Bartini's LT-table entities is deemed to be important.

Method development

Proceeding from the Maxwell's idea (1873) on the possibility of constructing a system of measurement units based on only two units — length L and time T — Bartini systematized and arranged all physical values in

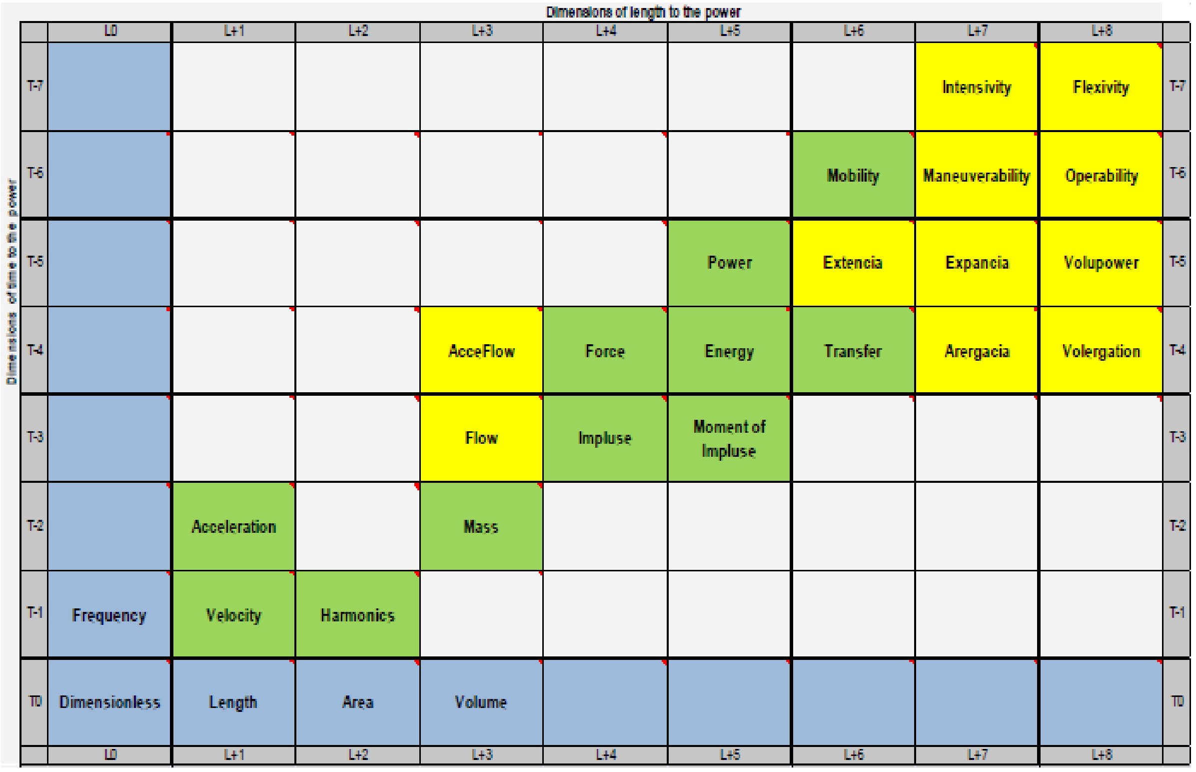


Figure 1. Matrix of physical laws and measurements

powers of L^m and T^{-n} in a special LT-table (Bartini, 1965). Let us specify the dimensionality of the following standard kinematic quantities in L-T coordinates: length — L^1T^0; mass — L^3T^{-2}; energy — L^5T^{-4}; moment of mass — L^4T^{-2}, m^4 / s^2 (in accepted units of transport work, t·km, through the conversion coefficient). In collaboration with Kuznetsov, Bartini suggested a quantity with dimensionality L^6T^{-4}, m^6/s^4, representing transmission of energy over a distance (*Transfer*) (Bartini, 1974). Later Obraztsova and Kuznetsov (Obraztsova, 1997) suggested a name for the transport version of this unit: "Tran" with dimensionality $[L^6T^{-4}]$ = (t·km)·km²/h².

In 2006–2011, Aleinikov, in collaboration with his US scientific team, filled 11 empty cells of the Bartini's LT-table with the corresponding peer entities and developed physical laws for the conservation of those entities. After the addition of those entities, the original Bartini's LT-table took on a form depicted in Figure 1 (Aleinikov, 2011). The table cells filled with the above-mentioned 11 new entities are colored in yellow.

Since 2001, the elaboration of the methodological approach to the estimation of transport and transportation energy efficiency, considering the squared delivery velocity, has been associated with the development of Bartini's ideas on geometric LT-systematization of physics laws, as well as ideas of Obraztsova and Kuznetsov (Kotikov, 2001).

Several author's studies (Kotikov, 2006, 2017a, 2017b, 2017c) show that the vehicle output and energy consumption should be brought into correlation with each

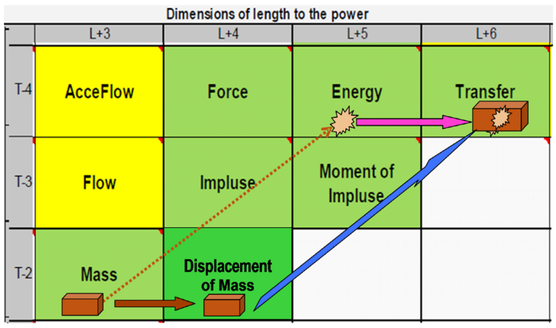


Figure 2. A diagram of output and energy consumption correlation at the level of the Transfer entity on the Bartini–Aleinikov's LT-table canvas (Kotikov, 2017a)

other (to obtain a dimensionless efficiency coefficient) at the level of the Transfer entity in the L6T-4 cell.

The author also points out that it is necessary to multiply the output (formed in the L4T-2 cell) by the squared velocity of cargo transfer, which corresponds to the diagonal transition within the table by two levels to the right and up: see a Bartini–Aleinikov's LT-table canvas fragment in Figure 2.

Identification of method variables and indicators according to the diagram in Figure 2 is given in Table 1. Let us note that the Linear transport work (Output W_1) and Linear transport service S_1 in this loop (see arrows in Figure 2) are taken with index "$_1$", which means D1 dimensionality and point-like nature of a serviced spatial object.

DOI: 10.23968/2500-0055-2018-3-3-3-9

Table 1. Identification of method variables and indicators according to the diagram in Figure 2

	L^3	L^4	L^5	L^6
T^{-4}		Force, N	Energy *E*, J	Transfer, Trn (Linear transport service S_1, t·km³/h²)
T^{-3}		Impulse	Moment of impulse	
T^{-2}	Mass, m³/s² (Mass *M, t*)	Moment of mass (Linear transport work (Output W_1), t·km)		

Further development of the methodology is construction of a series of estimates for spatial spheres' servicing based on Bartini's LT-table entities

In author's studies (Kotikov, 2001, 2006, 2017a, 2017b, 2017c), a methodology for energy efficiency estimation regarding vehicles and means of transport upon linear transportation (over the network) of transportation objects, with account for cumulative energy consumption during the life cycle of vehicles, was formed.

However, in areas with high business activity and the large number of goods and people, the pattern of distribution is as if "blurred" by the law of large numbers, smoothed down, switching from the network configuration to the field one. Some other transport phenomena also have field character: dispersion of exhaust gases over the area; noise fields; irrigation of agricultural fields, fire areas, etc. Visualization of transition from the network model to the field model is shown in Figure 3.

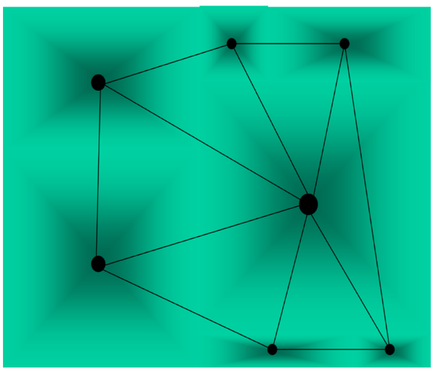


Figure 3. Transition from the network model to the field model

A similar picture becomes more and more relevant in a three-dimensional version: e.g. dispersion of exhaust gases in the volume over the city, coal heaping in open terminals, distribution of people in the 3D volume of a skyscraper (up to 10 thousand people in dozens of skyscrapers in Shanghai), etc.

By analogy with the linear case, when the author used the Bartini's LT-table *Transfer* L6T-4 criterion (see Table 1) to estimate cargo transportation energy efficiency, we will develop criteria for cases of utilizing the energy spent on transportation, upon the area (2D) and volume (3D) distribution of goods and/or people massifs.

For this purpose, let us use the Bartini–Aleinikov's matrix (Figure 1). Let us select the {L3–L8; T-2–T-4} fragment. As it was shown previously (Kotikov, 2017a, 2017b, 2017c), in case of linear transportation of cargo/people to a delivery/destination point, the *Transfer* entity (table cell) was used for the concentration of service S_1 and corresponding energy consumption *Trn*. In the energy layer of entities (T-4 row), it is the following product: Energy × L = Transfer (L6T-4 entity).

In case of cargo/people distribution throughout the area of delivery, it will be required to multiply the energy consumed by L². It is Arergacia = Energy × L × L (L7T-4 entity) on the Bartini–Aleinikov's canvas (Figure 1) (in another article, Aleinikov uses the Arergation term).

In case of cargo/people distribution throughout the volume of delivery, it will be required to multiply the energy consumed by L³. It is Volergation = Energy × L × L × L (L8T-4 entity) on the Bartini–Aleinikov's canvas (Figure 1).

Let us specify characteristics of new concepts (Arergation (Arergacia) and Volergation) in the form suggested by Aleinikov in 2007 (Aleinikov, 2007).

The Arergation entity (derived from **ar**ea + **erg**on) represents area distribution of energy. Its measurement unit is *Sergal*. The Law of Arergation Conservation has the following form:

Arg = Trn × L = L7T-4 = const;

1*Sergal* = 1Tran × 1m = 1J × 1m².

The Volergation entity (derived from **vol**ume + **erg**on) represents volumetric distribution of energy. Its measurement unit is *Natal*. The Law of Volergation Conservation has the following form:

Vrg = Arg × L = Trn × L2 = L8T-4 = const;

1*Natal* = 1*Sergal* × 1m = 1*Tran* × 1m² = 1J × 1m³.

This is a powerful scientific innovation. However, the following critical remark can be made (which in no way derogates from the merits of the Aleinikov's school): the names of entities are non-systematic. Moreover, Aleinikov even used people's names for measurement units. To construct a series, a systematic approach is preferable even in name creation. Let us try to perform this task.

Let us assign to the entities of the energy series (elements of the Bartini's LT-table T-4 row) names consonant with the *Energy* term (where the -gy particle carries the general meaning of the entity):

- let us replace *Transfer* with ***Linergy*** (derived from **lin**ear + **erg**on);
- let us replace *Arergation* (also known as Arergacia) with ***Arergy*** (derived from **ar**ea + **erg**on);
- let us replace *Volergation* with Volergy (derived from **vol**ume + **erg**on).

Using the above, we can build a diagram (see Figure 4) on the Bartini's LT-table canvas.

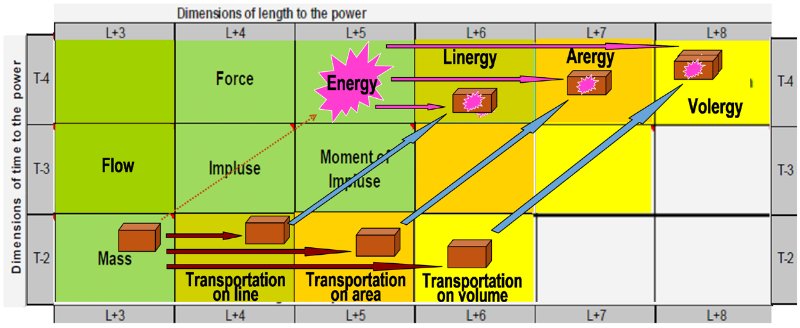


Figure 4. A new toponymy of entities and connection between them

Besides, we will use the -ation suffix (used in English for the formation of verbal nouns with process meaning) to identify the corresponding transfer processes (similar to the Transport–Transportation pair of related concepts):

• for linear transfer of energy — ***Linergation***;

• for energy distribution throughout a 2D area — ***Arergation***;

• for energy distribution throughout a 3D sphere – ***Volergation***.

It is presented in Figure 5 which can be considered a detailed elaboration of the diagram in Figure 4. Loops 1, 2, 3 in the corresponding table cells compare energy consumption for an idealized cargo transfer with the actual reduced energy consumption of the transportation system (see the methodology suggested by the author (Kotikov, 2017c)).

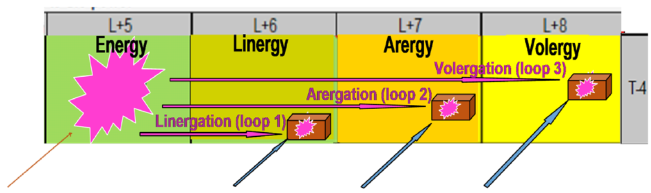


Figure 5. Detailed elaboration of Bartini's LT-table T-4 energy series concepts

Notations of quantities representing entities (similar to how *A, E,* or *W* represent the entity of *Energy*) are as follows:

for *Linergy*: *Lrg* with measurement unit Jm1 (derived from $J \times m^1$);

for *Arergy*: *Arg* with measurement unit Jm2 (derived from $J \times m^2$);

for *Volergy*: *Vrg* with measurement unit Jm3 (derived from $J \times m^3$).

Identification of new method variables and indicators according to the diagram in Figure 4 is given in Table 2.

Table 2. Identification of method variables and indicators according to the diagrams in Figures 4 and 5.

	L^3	L^4	L^5	L^6	L^7	L^8
T^{-4}		Force, N	*Energy E*, J	*Linergy, Lrg* (Linear transport service S1, t·km³/h²)	*Arergy, Arg* (Transport service of area distribution S_2, t·km⁴/h²)	*Volergy, Vrg* (Transport service of volumetric distribution S_3, t·km⁵/h²)
T^{-3}		Impulse	Moment of impulse			
T^{-2}	Mass, m³/s² (Mass *M*, t)	Linear transport work (Output W_1), t·km	Transport work throughout area (Output W_2), t·km²)	Transport work throughout volume (Output W_3), t·km³)		

Case Study

Let us give an example of calculation for two-dimensional distribution of transport work throughout the area (with regard to transportation in the megacity territory).

For a start, let us consider a simple analogy — area irrigation with a sprinkler with one sprayer (see Figure 6) (Frolova, 2017). The service of water distribution throughout the area of sprinkler coverage S2 consists in supplying a mass of water with a certain supply rate and more or less uniform distribution of this mass over the service area.

DOI: 10.23968/2500-0055-2018-3-3-3-9

If we refer to the sprinkler, then its *Arergy* is the energy spent by the system of water supply to deliver it to the nozzle and spray, multiplied by the spraying area. The service rendered by the system under consideration consists in area irrigation. This service is proportionate to the area serviced. That is why in this case the area is rightfully included into the *Arergy* criterion as a multiplier.

The scheme can be complicated by various sprinkler options and their systems (stationary sprinklers with multiple sprayers; single mobile sprinklers; systems of mobile sprinklers) providing both grid and contour irrigation (when irrigation is carried out using mobile devices moving only along the perimeter road (see Figure 7)) (Frolova, 2017). This latter option can be used as an analogue for the megacity issue.

Figure 6. Field character of water distribution using a stationary sprinkler with one sprayer

Let us note here that in all cases water (agent) is taken from some source (resource), and the calculation of *Arergy* should account for cumulative energy consumption not only for the actual spraying, but also for the operation of mobile devices, provision of water resources in the source (a canal, a reservoir), or, more precisely, energy consumption in the entire irrigation system.

The scheme under consideration can be easily applied to transportation and logistics in a zone or region. The simplest cases are production points, distribution centers, etc. But in case of production and distribution networks, point sources located at network nodes, jointly serve the territory by analogy with spraying (irrigation). Transportation in a city when importing the mass of commodities along outbound routes can be given as an example.

Let us return to Table 2. Linear transport output W_1 represents standard transport work in t·km.

Similarly, to bring the output for the area served W_2 (see Table 2) in correlation with the corresponding energy consumption, we multiply it by the squared velocity of cargo transfer; this corresponds to the diagonal transition within the table from the L5T-2 cell by two levels to the right and up — to the cell of the *Arergy* L7T-4 entity (Table 2).

Let us consider a hypothetical numerical example. The Leningrad Region represents a source of daily commuting for the core of the Saint Petersburg agglomeration. Let us accept the ground part of the administrative area of Saint Petersburg with an area of approximately 900 km^2 as this core.

This area is filled with industrial enterprises, educational institutions, trade enterprises and other places of visit. Although people move within the city network, let us "blur the network to make it seem like a field" (see Figure 3) and accept input flow distribution within the agglomeration core to be uniform.

Electric trains of the Saint Petersburg railway junction carry 80 million people per year. Let us assume that half of them — 40 million — are those who commute daily. The average train speed is 60 km/h. The average trip length is 60 km, i.e. the average time per a trip is 1 hour.

Annual transport work in the area (Area output W_2) is equal to:

W_2 = 40,000,000 passengers × 900 km^2 = 36·10^9 pass-km^2 = 36·10^{15} pass-m^2.

Area transport service:

$S_2 = W_2 \times V^2$ = 36·10^9 pass-km^2 × 60^2 km^2/h^2 = 1,296·10^{11} pass·km^4/h^2 = 1,296·10^{11} pass·km^4/h^2 = 36·10^{15} pass-m^2 × (60/3.6)^2 m^2/s^2 = 36·10^{15} × 277.777 = 10,000·10^{15} pass·m^4/s^2.

Despite the fact that servicing of passenger flows is different from servicing of cargo flows, we will additionally calculate the mass characteristic of the passenger flow. Taking a ratio of 1 ton ≈ 14 people (i.e. the person's mass is 71.43 kg), we can calculate the mass equivalent of the area transport service:

S_2 = 10^{19} pass·m^4/s^2 × 71.43 kg/pass = 71.43·10^{19} m^2·(kg·m^2/s^2) = 0.7143·10^{21} Jm2.

Let us calculate energy consumption. One carriage has 100 seats. Usually, trains have 4–12 carriages. Let us take 8 carriages, i.e. 800 passengers per one train. The hourly power of an electric drive of a train having 8 carriages amounts to 3,200 kW (SCBIST, 2018). In order

Figure 7. Contour irrigation: a) intermittent; b) continuous

to transport 40 million passengers, we need 40 million passengers/800 passengers/train = 50,000 train trips, one hour each.

Total energy consumption: 3,200 kW × 50,000 h = 160,000,000 kW·h =16·10^7 kWh × 3,600 kJ/kW·h = 576·10^9 kJ= 576·10^{12} J.

Transfer of this energy to the serviced area (transition from the L5T-4 cell to the L7T-4 cell, i.e. transition from the *Energy* entity to the *Arergy* entity) can be presented as follows:

Arg = 576·10^{12} J × 900,000,000 m^2 = 518.4·10^{21} Jm2.

Now, having two indicators (S_2 and *Arg*) for the L7T-4 cell of the Bartini's LT-table, we can determine the weight coefficient of energy efficiency regarding transport service in the agglomeration core by the mass of daily commuting:

$\eta_{Arg} = S_2 / Arg$ = 0.7143·10^{21} Jm2 / 518.4·10^{21} Jm2 = 0.00138 = 0.14%.

We should note that the equivalence of dimensions (Jm2) made it possible to calculate the dimensionless coefficient of energy efficiency. This will be rather convenient when comparing different options in optimization calculations for similar systems.

We should also note the very low value of the energy efficiency coefficient obtained. This can be explained by expectations of comfort during passenger transportation, and not by the mass density of the train load (in case of cargo transportation, instead of passengers, with full load of carriages, the η_{Arg} indicator would increase by 14 times). The mass density of the load will have a linear influence on the coefficient. At the same time, the delivery speed will have a quadratic influence: this will allow to estimate the Linergy (L6T-4) and Arergy (L7T-4) criteria.

Conclusion

Perhaps, the Arergy entity, the L7T-4 element of the Bartini's LT-table, for the first time has found its analytical application for calculating energy efficiency of transport services in the economic area — the core of the megacity agglomeration. The nature of quantitative estimation in the example is rather conventional.

However, in the author's opinion, the created method of territory servicing estimation is viable and subject to further development.

The author of this article is aware that he does not create any new entities. He is just confident in the fact that reformatting of unsteady concepts created by the predecessors will make it possible to construct and analyze future analytical models in the activity field under consideration in more transparent and understandable ways.

References

Aleinikov, A. (2007). Nine new laws of conservation: future science horizons. In: *Proceedings of the Allied Academies International Conference*, 6 (2), pp. 5–10.

Aleinikov, A., Smarsh, D. (2011). 11 new laws of conservation: expanding physics horizons for strategic management. In: *Proceedings of the Allied Academies' Internet Conference*, 13, pp. 130–131. Available at: http://www.alliedacademies.org/pdfs/Internet_Proceedings_Vol_13_2011.pdf (accessed on: 30.06.2018)

Bartini, R.O. (1965). Some relations between physical constants. *Reports of the Academy of Sciences of the USSR*, 163 (4), pp. 861–864.

Bartini, R.O., Kuznetsov, P.G. (1974). Multiplicity in geometries and physics. In: *Proceedings of the seminar "Cybernetics of electric power systems"*, p. 11. Available at: http://www.metodolog.ru/01380/01380.html (accessed on: 30.06.2018)

Frolova, L. (2017). *Sprinkler devices: types and application*. Available at: http://fb.ru/article/364163/dojdevalnyie-ustanovki-vidyi-primenenie (accessed on: 30.06.2018)

Kotikov, Ju.G. (2001). *Osnovy sistemnogo analiza transportnykh sistem [Fundamentals of system analysis for transport systems].* Saint Petersburg: Saint Petersburg State University of Architecture and Civil Engineering, p. 264. (in Russian)

Kotikov, Ju.G., Lozhkin, V.N. (2006). *Transportnaya energetika [Transport power engineering].* Moscow: Academia Publishing Center, p. 272. (in Russian)

Kotikov, Ju.G. (2017a). Estimation of transportation energy efficiency by Bartini criterion L6T-4. *Architecture and Engineering,* 2 (2), pp. 15–19. DOI: 10.23968/2500-0055-2017-2-2-15-19.

Kotikov, Ju.G. (2017b). Calculation of freight rail transport energy efficiency by Bartini criterion L6T-4. *Architecture and Engineering*, 2 (3), pp. 21–25. DOI: 10.23968/2500-0055-2017-2-3-21-25.

Kotikov, Ju.G. (2017c). Transport energy efficiency assessment on the basis of the life cycle with the attraction of the Bartini Transfer entity. *Architecture and Engineering*, 2 (4), pp. 21–25. DOI: 10.23968/2500-0055-2017-2-4-14-19.

Kotikov, Ju.G. (2018). Stages of quantomobile development. *Architecture and Engineering*, 3 (2), pp. 26–35. DOI: 10.23968/2500-0055-2018-3-2-26-35.

Leonov, V.S. (2010). *Quantum energetics. Volume 1. Theory of Superunification.* Cambridge: Cambridge International Science Publishing, p. 745.

Obraztsova, R.I., Kuznetsov, P.G., Pshenichnikov, S.B. (1997). *Inzhenerno-ekonomicheskii analiz transportnykhsistem [Engineering and economic analysis of transport systems].* Novosibirsk, p. 156. Available at: http://lib.uni-dubna.ru/search/files/ur_enjekan/~ur_enj-ek-an.htm (accessed on: 30.06.2018) (in Russian)

SCBIST (2018). Electric trains. FEATURES OF THEIR WORK AND THE DESIGN. Available at: http://scbist.com/zheldor/elektrovoz/elektrovoz_44.html (accessed on: 30.06.2018)

DISAPPEARED HISTORIC OPEN SPACES IN THE CENTER OF SAINT PETERSBURG

Leonid Lavrov[1], Fedor Perov[2]

[1,2] Saint Petersburg State University of Architecture and Civil Engineering
2-ya Krasnoarmeiskaya st., 4, St. Petersburg, Russia

[1] leonid.lavrov@gmail.com

Abstract

The paper questions the official statement that the system of open spaces in the historic center of Saint Petersburg has preserved the "authenticity of its chief components". Conditions for the formation and subsequent reconstructions of Theater Square and areas adjacent to the Neva river are analyzed.

The nature and scope of changes those areas undergone in the latter half of the 19th and early 20th centuries are identified. It is shown that Senate, Admiralty, Rumyantsev, Collegiate squares and Razvodnaya ground (used for the changing of the guard) lost their transparency which disturbed the relationship between the Neva water area and city open spaces, and that significant damage was caused to the city center panorama. It is noted that the center landscape potential was neglected due to that reason. Proposals are made to recreate the lost transparency of the city center public spaces.

Keywords

Landscapes of the historic center of Saint Petersburg, open spaces, reconstruction.

Introduction

It is generally acknowledged that one of the architectural features of the Saint Petersburg historic center is its "single continuous open space formed by rivers and canals, squares, avenues, streets and gardens" (Shvidkovsky, 2007). When Saint Petersburg was suggested to be included in the World Heritage List, the corresponding Retrospective Statement of Outstanding Universal Value of the World Heritage Site "Historic Center of Saint Petersburg and Related Groups of Monuments" pointed to the specific character of its spatial framework as a substantial argument: "The full-flowing Neva bequeathed the city an exceptional spatial scale and wealth of spectacle...

The Neva water spaces were natural extensions of the system of city squares" (Retrospective Statement of Outstanding Universal Value of the World Heritage Site “Historic Center of Saint Petersburg and Related Groups of Monuments"). It was further emphasized that "the initial city layout and a large portion of the original structures in Saint Petersburg's historic centre are testament to its Outstanding Universal Value... integrated value as the Historic Urban Landscape." However, the suggested opinion that "the site has preserved the authenticity of its chief components" seems overoptimistic. The present paper deals with the reliability of such assertion. Moreover, it is clarified to what extent the information on the development pattern can be used to assess the state of urban landscapes.

Terms and Definitions

An analysis of terms used to describe open spaces in various fields of urban planning revealed some fundamental discrepancies in definitions of key concepts.

"Public spaces represent a part of the urban environment that is constantly available for people

DOI: 10.23968/2500-0055-2018-3-3-10-21

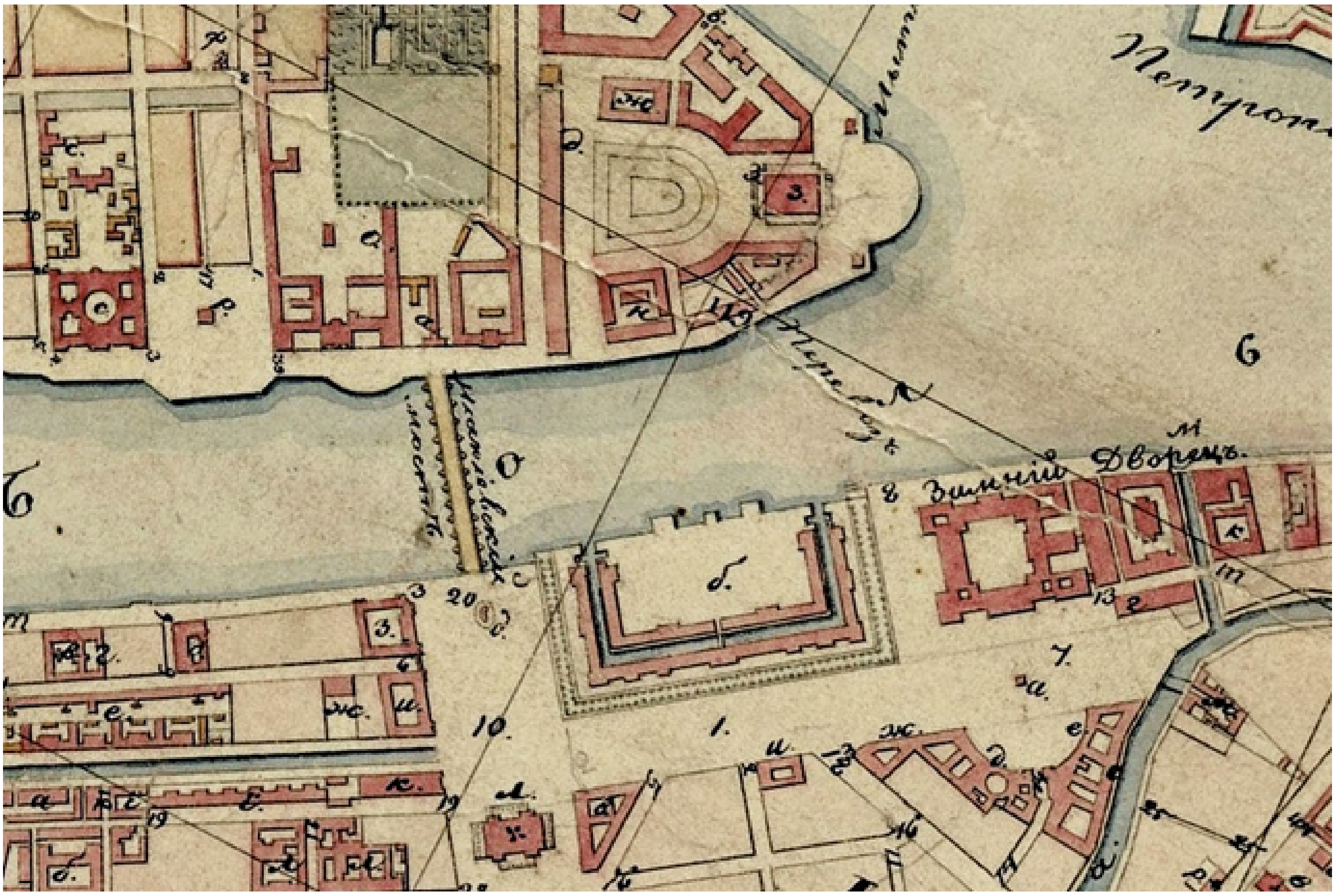


Figure 1. A map showing the system of Saint Petersburg open spaces at its golden age

free of charge... among places where urban social life takes place, the following can be mentioned: squares, embankments, streets, pedestrian areas, parks" (http://estp-blog.ru/encyclopedia/13956/).

The commonly used definition suggested by the Central Research and Design Institute for Urban Development qualifies "undeveloped territories in general, including water and park systems, main avenues, embankments, esplanades, pedestrian areas, squares, boulevards and other elements of the urban planning pattern that form a system of open spaces" as urban open spaces. Such approach is reflected in black-and-white urban planning layouts where areas occupied by permanent structures are highlighted ("schwarzplan"). It is understood that white spots represent undeveloped "open" spaces. Such information can be useful when handling construction projects, laying utility lines, etc., but it is insufficient to assess visual characteristics. In particular, gradation of urban green areas by their visual characteristics existing in landscaping is not considered. Green construction comprises the following:

- enclosed spaces (areas and groups of tree plantations that exclude or substantially limit visual connections);
- semi-open spaces (with deeper visibility, greater visual connections with adjacent areas);
- open spaces (glades, ponds, areas not occupied by dense plantations and facilities) (https://znaytovar.ru/gost/2/Metodicheskoe_rukovodstvoMetod2.html).

Thus, it turns out that undeveloped green areas which are automatically qualified by city planners as open spaces may actually belong to enclosed spaces in terms of landscaping.

The influence of greenery planting on landscapes in Saint Petersburg was noted by B.M. Kirikov in the latter half of the 19th century. He treated the concepts of "openness" and "transparency" as synonyms and stated that in the period under review the city "was losing its openness, transparency... Petersburg began "to fear the emptiness". The city... sort of sought to absorb the area (through development of areas or greenery planting)" (Kirikov, 2006).

A classic example of open space is a city square. According to the Internet, "a square is an architecturally organized open space surrounded by buildings and green areas, being a part of the urban space system" (http://dic.academic.ru/dic.nsf/ruwiki/1778770).

In summary, it can be noted that transparency of an open space, i.e. absence of interferences with the visual perception of its limiting elements (e.g. facade fronts outlining the square), shall be considered as the determining feature of an open space.

Squares of Saint Petersburg

Evolution of Saint Petersburg development is characterized by the fact that central Palace, Mikhailovskaya and Saint Isaac's squares which made the city famous were formed on the basis of the "Alexander's Empire Style" over a short period — in the 1800–1840s. Although, a plan for their formation developed by the Commission for Saint Petersburg and Moscow Stone Construction existed since the 1760s. Indeed, outlines of the squares could be seen on official maps, but the plans were implemented later. A book published by J.G. Georgi in 1794 lists few squares of the late 18th century on the Admiralty side: "irregular Petrovskaya and St. Isaac's squares", "Palace square in the form of an amphitheater", "Tsaritsyn meadow near the Summer Gardens, a square near the Kamenny Theatre and Sennaya square". Vasilyevsky Island had a "large irregular, unpaved, partially swampy square surrounded by the buildings of the Academy of Sciences, State Collegia, Stock Exchange and Customs storehouses" and a "four-cornered empty space" on the banks of the Neva river at the Academy of Arts (Georgi, 2001b) .

The situation began to change rapidly at the very beginning of the 19th century. Saint Petersburg was developing fast. Its population was already over 200,000 people, and the city was among the leading European metropolises. Young Emperor Alexander I ascended the throne. He perceived the renewal of the capital appearance as an important personal task. In the 1800–1840s, Saint Petersburg matched to the intention of Peter the Great — an image of an imperial city was created. In this short period, a magnificent ensemble of Saint Petersburg central squares was formed which gave the city features of a world-class capital.

Theater square

This square holds a special place in the city's history: first, it became the first regular square of the city; second, reconstructions performed here were more radical than in any other square of the historic center, therefore, its modern appearance almost does not remind the remarkable past.

In his description of Saint Petersburg in the late 18th century, J.G. Georgi mentioned "a square near the Kamenny Theater" (nowadays it is Theater Square). It was a new urban-planning project, history of which began in 1775, when, at a wasteland that was allocated for residential buildings, theater construction began according to a design of A. Rinaldi. Over a short period (1782–1787), a navigable canal was constructed from the Moyka river to the Fontanka river, and Lithuanian castle (architect I.E. Starov) and Lithuanian market (architect G. Quarenghi) were built on its banks. Outlines of the rectangular square were denoted by houses of local inhabitants. There is no information about any projects for its development — the appearance of a regular urban-planning organism was a result of a strict system of city development management, effect of construction regulations. By the end of the 18th century, a regular public open space was formed here. The square is characterized by large dimensions and compositional symmetry. Its image was determined by the following dominant elements: the theater building, the arcades of the Lithuanian market included in its space, and the Kryukov canal with its granite embankments and ornamental fencing (Figure 2).

In 1801–1803, by order of Alexander I, Thomas de Thomon reconstructed the Bolshoi Kamenny Theater, which radically changed the nature of its appearance and assigned the square a new role of a center of city public life. Numerous works of Saint Petersburg landscape painters (including F.Ya. Alekseev, K.P. Beggrov, G. Quarenghi, K. Kollman, G.L. Lory and M.G. Lory, A.E. Martynov, A. Mayer, B. Patersen, J. B. De la Traverse) testify to its popularity. Their works demonstrate that the first parade square in Saint Petersburg was formed and actively functioned around the Bolshoi Kamenny Theater: at that time there still was a system of fortifications around the Admiralty, and the site of future Mikhailovskaya Square had a marshy swamp — the origin of the Glukhaya river.

In 1849, a finishing stroke was given to the Theater Square — in its center, right on the bank of the Kryukov canal, Imperial Circus Theater was built. "In terms of architecture, the sovereign had a bad taste and chose an extremely unsuccessful location for his pet project, the first permanent circus in Saint Petersburg," wrote well-known Saint Petersburg expert L. Lurie (Printseva, 2016). The circus theater burned down in 1859, but Mariinsky Theater was quickly erected in its place. Later it was expanded several times. Despite the protests of the art

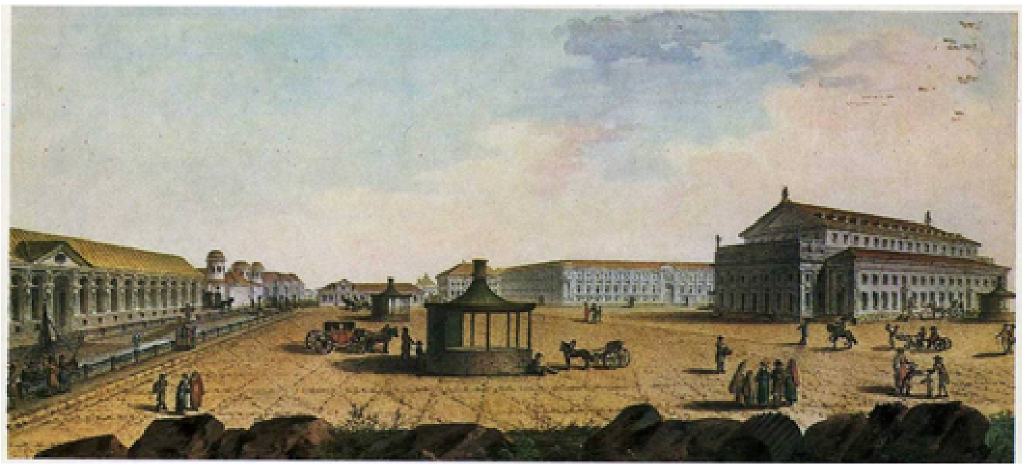


Figure 2. Theater Square in the late 18th century. The Bolshoi Theater in Saint Petersburg. A fragment (by Jean Balthazard De la Traverse, from the collection of I.S. Zilbershteyn)

Figure 3. A layout of Theater Square in the early 19th century (left) and in the late 20th century (right)

community, the dilapidated Kamenny Theater was rebuilt for the needs of the Conservatory. Results of the buildings' reconstruction were summarized by A.N. Benois in 1902: "In place of the Bolshoi Theater by de Thomon, a hideous construction consisting of half a dozen "facades", like those that are drawn by first-year students, suddenly appeared... Trying to keep up with its neighbor, the Mariinsky Theater dressed up in a clownish outfit of the so-called "Deutsche Renaissance" (Benois, 1902).

The open space of the square shrank and split up into several parts; it was cut off from the water area of the Kryukov canal and from the arcade of the Lithuanian market. The style of dominant buildings completely changed, urban amenities became different. In the early 19th century, the square near the Kamenny Theater could be compared with Saint Isaac's or Palace square, but by the early 20th century it became similar to unimpressive European squares of the era of commercial construction. We can only regret that the brilliant past of Theater Square is over and nowadays it rarely attracts attention of both experts and lovers of the Saint Petersburg antique. Perhaps, this is due to the fact that only a few background buildings remained from the first regular square. There is no hope that Theater Square will regain its former glory and Saint Petersburg artists will strive to capture its beauty.

Collegiate square

At first, is was formed as a main square of the new capital, but later it became a storage area for the port, and then it was converted into an area of a palace medical clinic.

In a description of Saint Petersburg of the late 18th century, a "large irregular, unpaved, partially swampy square surrounded by the buildings of the Academy of Sciences, State Collegia, Stock Exchange and Customs storehouses" is mentioned (Georgi, 2001b).

Its name was not mentioned. At that time, it was called Collegiate square (in honor of the building of the Twelve Collegia) or Academic meadow (reflecting the semi-rural nature of the space near the Academy of Sciences buildings). Collegiate square was the first major urban-planning project which began to take shape on the deserted Vasilyevsky Island. In the early 1720s, outlines of residential quarters were just beginning to appear, soldiers and builders were sleeping in huts and tents, and stone buildings of the Twelve Collegia with a 400-meter facade and Customs merchant center with a 700-meter perimeter emerged at the Spit.

There were no such giant buildings, which were supposed to demonstrate Europe the greatness of the new Russian capital, at a distance of hundreds of miles neither in Russia nor in the Baltic countries. However, such ambitious plans required tremendous efforts. The soil under the future main administrative building of the Russian Empire turned out to be extremely swampy. In order to achieve the desired architectural effect, it was necessary to fill the swamp with soil and stones. 250 people operating ten pile drivers drove dozens of piles into the ground each day (http://www.ipetersburg.ru/zdanie-dvenadcati-kollegiy/). More than 2,000 piles formed the foundation base. A canal for drainage was dug along the main facade (Sorokin, Semenov, 2003). By the middle of the 1730s the construction works were completed. The main 400-meter facade of the Twelve Collegia began to face the central water area of the Neva river.

Further reclamation of the swampy lowland slowed down. It was decided to reduce the amount of construction works and outline the area along the perimeter by trade galleries only. Peter I believed that such shops would revive the area. The collegia (administrative institutions) located in the area and the "cabinet of rarities" (the first Russian museum) nearby could attract only few people. There is evidence to the fact that the chief attendant at the Kunstkamera was allocated 400 rubles a year to treat the visitors. That bait was long used. "According to J. Staehlin, even during the reign of Empress Anna Ioannovna, the visitors were treated with coffee, sandwiches or vodka,

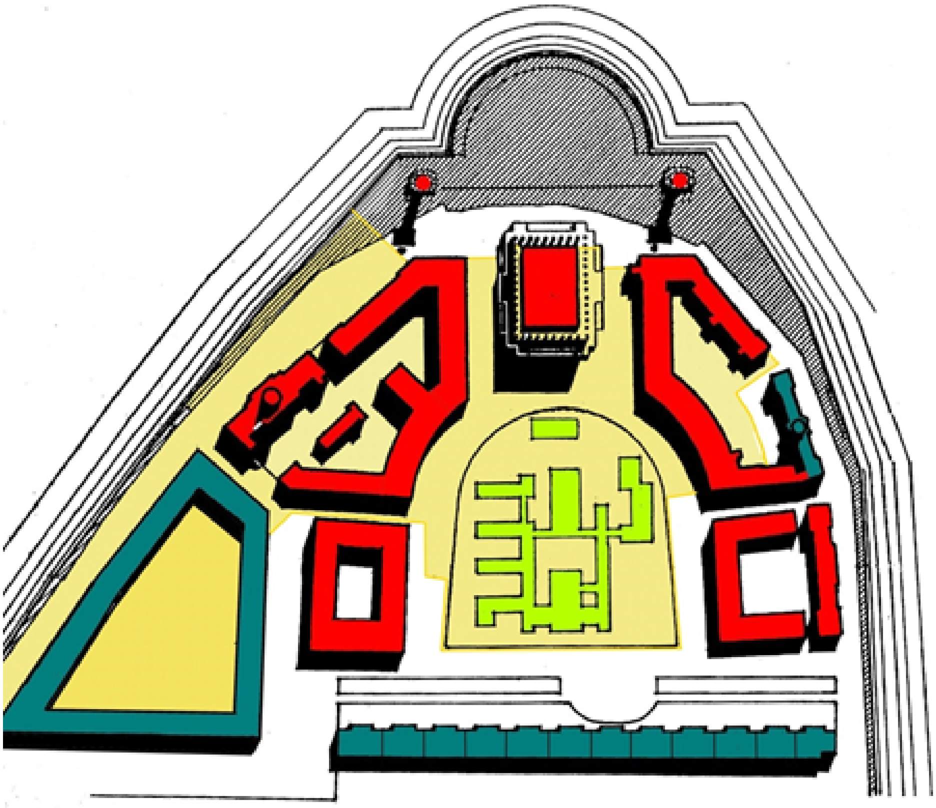


Figure 4. Allocation of trading port and customs facilities at the Spit of Vasilyevsky Island in 1891 (Gruzdeva E.N. Zoological Museum at the Spit of Vasilyevsky Island (according to the documents of Saint Petersburg Branch of the Archive of the Russian Academy of Science) http://www.ranar.spb.ru/files/visual/Zoomuseum/Zoo-5.jpg, access date: 03.06.2018). Yellow color indicates the restricted area of the customs and port. Grey color indicates buildings constructed in the first third of the 18th century; red color — buildings constructed in the first third of the 19th century; green color — buildings constructed in the late 19th century.

and the Kunstkamera was open to all social classes without exception" (https://www.e-reading.club/chapter.php/1011791/4/Sindalovskiy_-_Sankt-Peterburg_-_istoriya_v_predaniyah_i_legendah.html). Peter I repeatedly raised the topic of shops' arrangement. In 1724, the Office of the Emperor wrote: "The intention of His Imperial Majesty was to have shops of Gostiny Dvor (merchant market) around the square as well as in the lower apartments of the collegia on the front side" (http://artyx.ru/books/item/f00/s00/z0000005/st007.shtml). However, this urban-planning project was not completed. After the death of Peter I, the development activity in the square began to slow down. The Kunstkamera, Twelve Collegia, and Customs merchant center were managed to be completed, but no shops appeared. There was no movement in the square.

In the end of the 18th century, a new stage of the square development began. In 1783–1797, according to a project of J. Quarenghi, Main Building of the Academy of Sciences, Novobirzhevoy Gostiny Dvor, buildings of the Northern warehouse of the Stock Exchange were constructed. In 1805, Alexander I assigned Thomas de

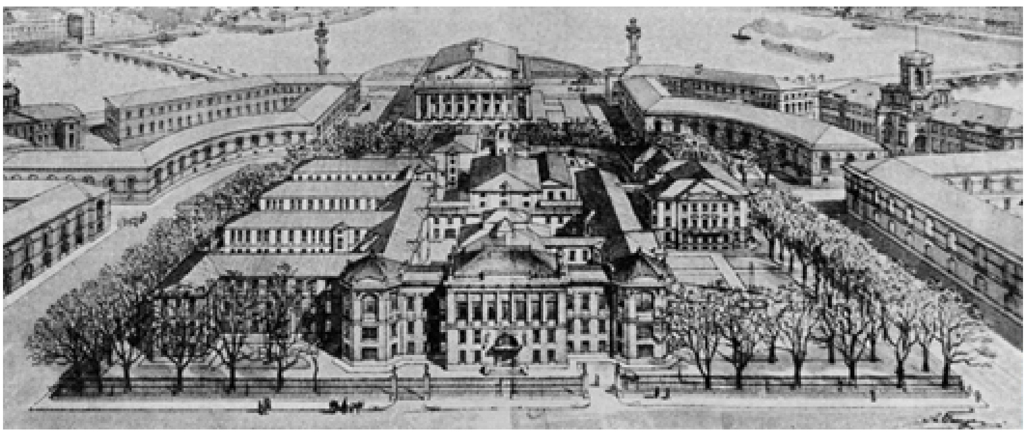
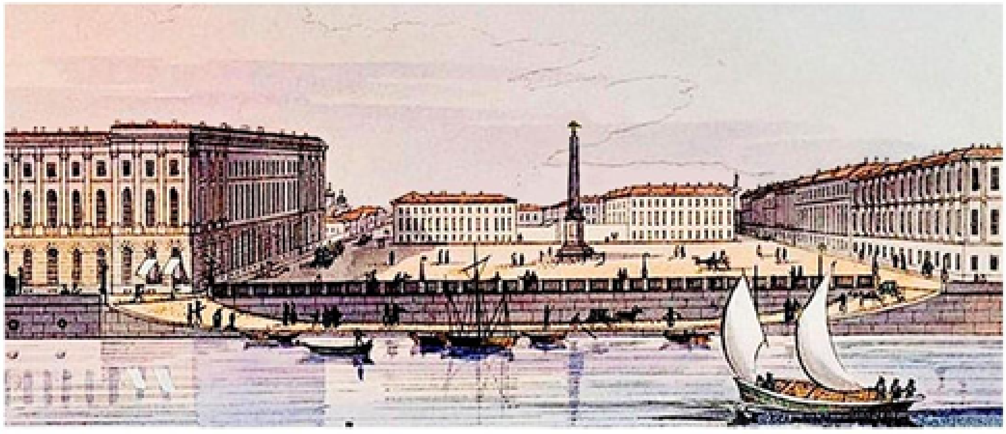


Figure 5. A project for the allocation of Imperial Midwifery Institute buildings at the site of the Customs (Tamozhenny) garden (picture by L. N. Benois). The chimney of the boiler room is conventionally not shown



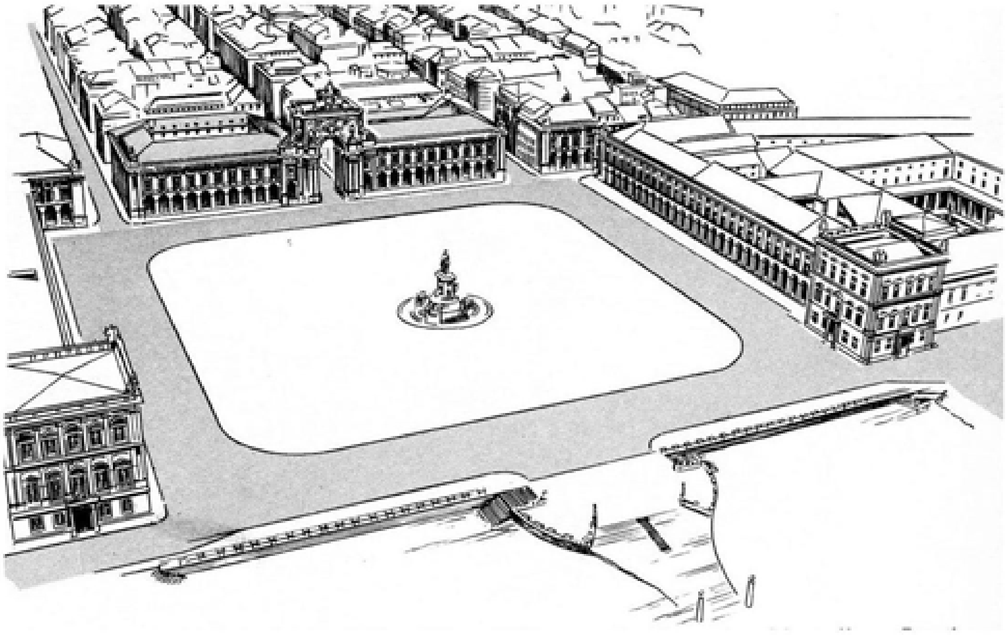


Figure 6. Top: Rumyantsev Square on the banks of the Bolshaya Neva. 1830s. K.P. Beggrov. Lithograph "Academy of Arts and Rumyantsev Obelisk" (fragment) (Nancy Municipal Library. File: Académie des beaux-arts, obélisque Roumiantzoff, album russe de Lisinka Poirel.jpg, access date: 10.07.2018). Bottom: a layout of Praça do Comércio on the banks of the Tagus River in Lisbon (Koch W., 2014)

Thomon to reconstruct the unfinished building of the Stock Exchange at the Spit (a relatively small building with a trading floor of 900 sq. m). The project quickly evolved into a concept of radical landscape changing in the very center of Saint Petersburg. Along with Thomas de Thomon, A. Zakharov, J. Quarenghi, and I. Luchini participated in its development and implementation. They preserved and utilized the heritage left by D. Trezzini and G. Chiaveri. An ensemble including Birzhevaya (Stock Exchange) square with a huge semicircular public garden and rostral columns as well as Collegiate square located among the buildings formed.

It could be assumed that by 1830 the dreams of Peter I and D. Trezzini about a large regular square like squares of an ideal city came true. It had a symmetrical composition, distinct outlines, and in terms of sizes it was comparable to Palace square. In terms of its artistic and urban-planning features, it was comparable to Mikhailovskaya square in Saint Petersburg, Place Vendôme in Paris. It also had such additional advantage as gaps between the buildings, thanks to which the Neva river could be viewed from there. In the appearance of the buildings, the Petrine Baroque and Alexander's Empire Style were combined, creative ideas of famous architects — D. Trezzini, J. Quarenghi, A.D. Zakharov, Thomas de Thomon, and I.F. Luchini — were brought to life.

However, the unique character of this masterpiece of urban-planning art went unnoticed both by townspeople and experts. No images of the square have been preserved. The specifics of its functional purpose manifested: instead of shops intended by Peter I, customs warehouses were located along its perimeter. In 1827, in its central part, a public garden was laid out; later it was decided to use it as a storage area. In order to protect the goods from possible floods, the ground level was significantly elevated and a dam system was constructed. Metal grilles were installed in two rows along the perimeter (Nikitenko, Sobol, 2002). Most of the square became a part of the the port's restricted area. It was fenced off due to the customs border and, therefore, became inaccessible to townspeople. Over-sized goods were stored in the area. Temporary overhangs and sheds were built there (Figure 4).

The liquidation of the trading port site at the Spit of Vasilyevsky Island, which occurred in the end of the 19th century, led to a radical change in land use, which was followed by the transformation of the historic buildings. Despite the protests of the creative intelligentsia, the Old Gostiny Dvor was destroyed to clear the site for the construction of a Ministry building. The Academy of Sciences, which got the Southern warehouse, “decorated” its main facade with an overhead portico, and from the opposite side a floor was added, which violated the symmetry of Collegiate square. However, the unique square ceased to exist even in black-and-white layouts as Imperial Midwifery Institute ("Ott's clinic") was built instead of it (Figure 5).

No criticism followed. Perhaps this was due to the fact that it was about the development of the port area or perhaps this was due to the fact that the author of the project was a recognized architect, and the initiator of the construction was the empress herself. These days, Saint Petersburg art experts prefer to avoid analyzing those changes and consider the building as an “exemplary in terms of its functional organization” (Kirikov, 2006).

Moscow experts point out that the design solution was “not absolutely coordinated with the responsible urban-planning organization,” and even the use of the pavilion principle of planning was inappropriate in this case. “The placement of a new large structure in the center of the historic ensemble does not meet the interests of preserving the latter. By occupying the area between the Stock Exchange and the University, the clinic complex disturbed visual connections between the facilities of the ensemble, which made it difficult to perceive it as an integral composition” (Kirichenko, 2010). We have to agree with professor V.G. Lisovsky who refers the reconstruction of the Spit of that period to "urban-planning vandalism" at the turn of the century (Lisovsky, 2004).

Rumyantsev Square

Rumyantsev square is a typical example of the use of orthogonal system resources for the formation of open public spaces. Some monotony typical for the development of the historic part of Vasilyevsky Island is softened by its direct visual connections with the water area of the Bolshaya Neva. Unfortunately, those few squares that existed in the end of the 18th century and represented a transition stage from river expanses to corridors of streets have disappeared from the map. In particular, J.G. Georgi found it necessary to note that “between the Land Cadet Corps and the Academy of Arts, there is a beautiful unpaved, four-cornered empty space on the right bank of the Neva river” (Georgi, 2001b)..

At first, there was Menshikov market, and then — an on-site area for the Academy of Arts construction. In the 1790s, the territory was used as a parade ground for the Cadet Corps. In 1818, at the suggestion of C. Rossi, Rumyantsev obelisk with a height of more than 20 m was erected in the center of the square, emphasizing its urban-planning significance.

The regular space flanked by clearly delineated facades and supplemented by the obelisk was facing the water and became a front square linking the water area of the Bolshaya Neva with Lines 1 and 2 stretching towards the Malaya Neva. The connection of the square with the water was emphasized in the 1830s. For this purpose, the river bank was shaped with a two-tier granite embankment with two symmetrical rampants on the sides. The square and obelisk were perfectly visible from the English Embankment and even from the foot of the Bronze Horseman. The resemblance of Rumyantsev square and Praça do Comércio in Lisbon surprisingly unfolded (Figure 5, 6).

The central square of the Portuguese capital acquired European fame as an example of effective and dynamic reconstruction of the city destroyed by a catastrophic earthquake in 1755. Restored Praça do Comércio (180 x 200 m), which used to be considered one of the largest in Europe, is almost the same as Rumyantsev square in terms of size, configuration, compositional symmetry, wide connection of open space with the water area, set of accent elements (a berth on the embankment and a monument in the center). However, the main square of the Portuguese capital was distinguished by luxurious facade decoration.

The situation on the banks of the Neva river changed when the functional load of Rumyantsev square decreased. When cadets stopped marching after the death of Nicholas I, the large unpaved territory became empty. In 1867, at the expense of merchant S.F. Solovyov, the owner of two houses on Rumyantsev square, a garden was laid out in front of his windows. Trees were growing uncontrollably as they were not cut, and over time the overgrown green mass filled most of the square. The green massif was so dense that the 20-meter Rumyantsev Obelisk was visible only through a narrow gap in the central alley of the garden, therefore, in 1913, the Academy of Arts considered the issue of moving the monument to the Field of Mars again (Sindalovsky, 2012). At the present time, this place continues to be designated as a square on the city map, but in fact there has been no open space for a long time.

The dense mass of high greenery fills the area, the functional connections of the garden with the embankment are completely suppressed by traffic flows, the unique potential of view cannot be used. The so-called square can no longer be considered an element of the system of open spaces of the city historic center, and its role in public life has been minimized.

DOI: 10.23968/2500-0055-2018-3-3-10-21

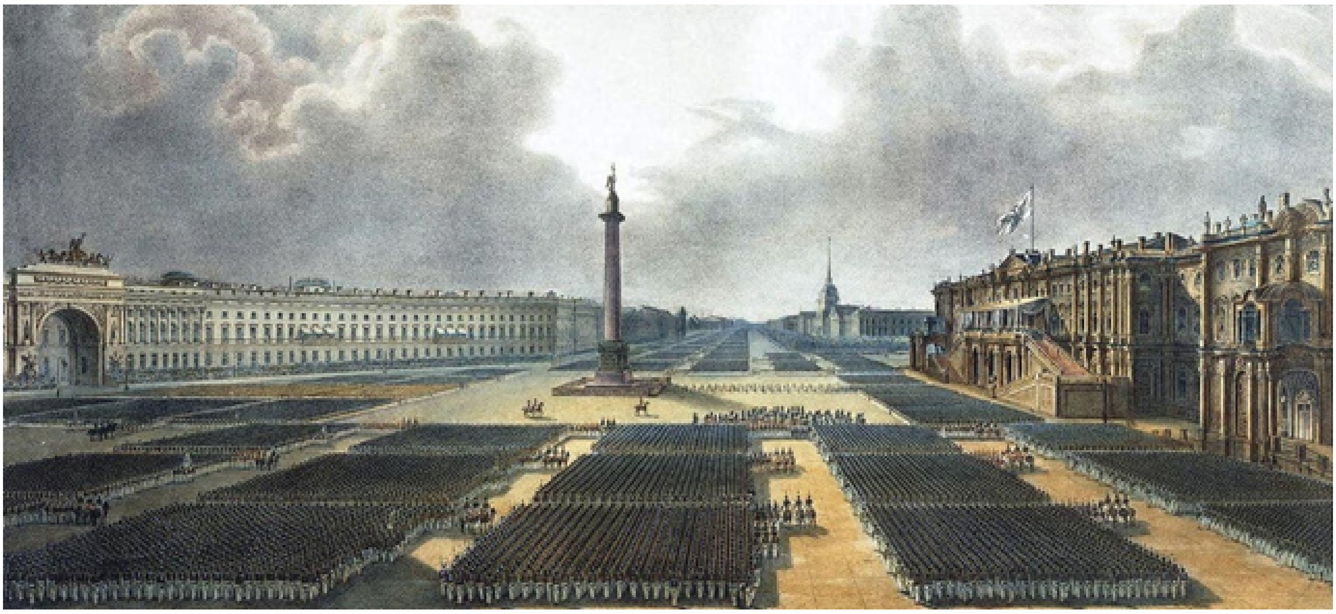


Figure 7. Bichebois, L. P.-A. Bayot A. J.-B. Ceremonial Unveiling of the Alexander Column (fragment) (http://www.hellopiter.ru/Alexandria_pillar_pic.html)

Central Squares Ensemble on the Admiralty side

Dimensions of this open space formed in the first third of the 19th century in the heart of the Russian capital are unique. As early as in 1794, J.G. Georgi did not pay special attention to those dimensions and, listing squares in the area, he noted a low level of amenities: "irregular Petrovskaya and St. Isaac's squares", "Palace square in the form of an amphitheater" (Georgi, 2001b).

At that time, the Admiralty dominated in the central development on the southern bank of the Neva river. K.P. Batyushkov described it as "a hideous large factory surrounded by drawbridges, deep dirty ditches filled with boards and logs" (Batyushkov, 1978). In 1805, Alexander I decided to start improving the territory adjacent to the Winter Palace. A contemporary of the time described "wild and sorrowful disharmony of the Admiralty that due to the height of the earth mound also seemed lower and darker: the view of that discordant scene was unbearable... The necessity to rebuild this important building did not escape the considerate attention of the Emperor!".

A.D. Zakharov was instructed to suggest options for Admiralty reconstruction. His concept allowed preserving the existing structures in times of austerity to the maximum. He described his idea in a note given to admiral P.V. Chichagov: "During the development of this draft project, my first rule was to secure benefits for the Treasury. Therefore, I decided not to break old walls and foundations, and that is why only several bare walls were added...". The project was approved in 1806, construction works started. Main changes in the existing buildings reflected the unity of functional, structural and aesthetic adjustments:

- window apertures in the existing walls between risalits were immured next but one. It allowed not only enlarging the facade scale but increasing the bearing capacity of the structure and providing a possibility of adding structures;
- with the consideration of the bearing capacity of the existing walls, the height of walls was increased from 9.92 to 16.51 m. It allowed arranging an additional storey and forming the desired proportions of the facade.

As V.G. Lisovsky noted, "due to variations of several forms, Zakharov managed to achieve the sense of wealth and polyphony in the Admiralty architecture" (Lisovsky, 2004).

In parallel with the reconstruction of the Admiralty buildings, reformation of the adjacent territory was performed. According to the Zakharov's project, the canals of the demolished Admiralty Fortress should be reconstructed and have a representative appearance modelled after the Moyka embankments, i.e. the banks should be faced with granite, cast-iron fencing should be installed, and stone bridges should be arched over. However, for economy reasons, the canals were filled up (Shuysky, 1989).

By the beginning of the 1820s, the center of Petersburg transformed radically. A system of large squares formed in place of the former glacis around the Admiralty. Admiralty square appeared in front of the 400-meter main facade. It connected the transformed St. Isaac's and Petrovskaya squares with Palace square. Continuous open spaces embraced the Admiralty from all sides and joined the "main square" of Saint Petersburg which was the majestic water area of the Neva river. This spatial system could be characterized as a core of the city urban-planning skeleton — a "single continuous open space formed by rivers and canals, squares..." (Shvidkovsky, 2007). Streets and canals were stretching to this area commanding a view of the most significant buildings.

While distinguishing architectural advantages of the reconstructed Admiralty, K.P. Batyushkov paid attention to new perspectives: "The Admiralty reconstructed by Zakharov turned into a beautiful building and became an adronment of the city. <….> The building is surround by a beautiful boulevard with lindens protecting against sun rays. It is the only lovely promenade providing a view of the most majestic and beautiful scenes of Petersburg: the

Figure 8. Admiralty square. A photo of the 1860s.

Neva river, Winter Palace, splendid buildings of Palace square forming a semicircle, Nevsky prospekt, Saint Isaac's square, Horse Guards Manege reminding of the Pantheon, charming building by Quarenghi, Senate, monument to Peter I and again the Neva river with its embankments!" (Batyushkov 1978).

The scale of this gigantic open space was amazing — it was more than twice larger than the Field of Mars. A huge site — the place where Winter Palace cows pastured a while ago — became an ideal place for ceremonial parades. Canvases of artists of that time show how harmonically infantry squares fit into the designated space (Figure 7).

The Central Squares Ensemble is rightfully considered as an outstanding piece of architectural and urban-planning art, however, its functional potential was significantly limited. According to Stolpyansky P.N., normally "Admiralty square gave a very bad impression". In proof of his statement he provided the following description of a contemporary: "Most of the day Admiralty square is empty.

One of the newspaper satirists even called it Admiralty prairie as it looks like a cut made inside the capital and filled with historic buildings, but not so vibrant as the center of the outstanding capital should be... Where are people? There are small alternating crowds by public offices (city governor's house thereafter), groups of people on the steps of the Senate and Synod, some carriages, some pedestrians, but that does not satisfy curiosity and a desire to see a spectacular view in the center of Saint Petersburg" (Stolpyansky, 1923). A photo of the 1860s represents the everyday life on central squares (Figure 8).

In 1872, in place of the Admiralty Fortress fortifications, a garden was started. The project was completed by 1874, "under the enlightened governance of Adjutant General Greig, the President of the Russian Horticultural Society, an expert in botanics; the works were performed by chief botanist of the Imperial Botanical Garden, active state councillor Regel, and collaborating botanists Bergman and Hedwig (Stolpyansky P.N., Old Petersburg. Admiralty island. Labourers Garden. https://coollib.com/b/343277/read, access date: June 24, 2018). Participation of architects was not reported. Architectural and artistic peculiarities of the site were not considered. The huge urban-planning potential was neglected.

The garden became an impressive display of dendrology treasures in the vast territory in the center of Saint Petersburg but it could not be considered as a landscape architecture artwork. Neither numeour sculptures nor various pavilions and kiosks could save the situation. Flaws in the project became apparent rather quickly. To eliminate those, replanning was performed repeatedly, and in 1890, by order of Alexander III, high overgrown trees were cut out on the land plot around the Bronze Horseman.

In 1902, Razvodnaya ground located between the Admiralty and the Winter Palace was completely transformed (its space was facing the Neva river thus providing visual connections between the river and Palace square). Private (Sobstvenny) Garden (for promenades of imperial family members exclusively) within the safety zone in front of the imperial residence was arranged in this place. Within a short time, the Alexander Garden land plot to the east of the Admiralty was completely liquidated, and the vast territory was enclosed by a massive stone fence with a high grill above. Those structures completely separated the spaces of the central squares from the Neva river. Meanwhile, the anti-terrorist system was non-demanded: the imperial family preferred to stay in Tsarskoye Selo and the Private Garden remained empty (Zimin, 2012).

Famous art expers of that time, who had a chance to see the Central Squares Ensemble in all its glory, noted the significance of city losses:

- I.E. Grabar: "Unfortunately, the entire square in front of the main facade of the Admiralty, which added to the impression that the author wished to make, is planted with garden plants. The square has disappeared, beauty and

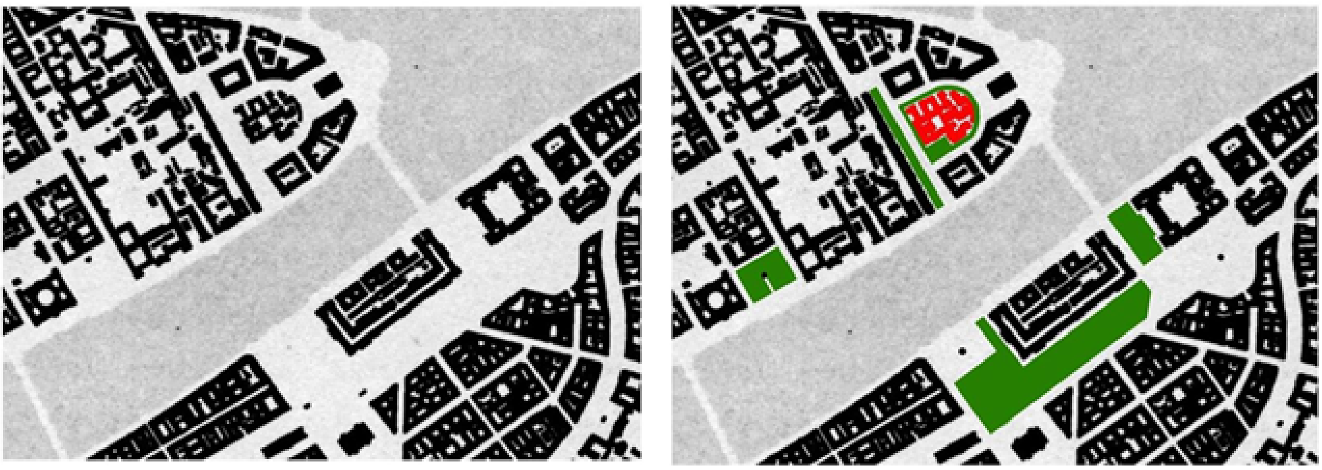


Figure 9. A system of open spaces in Saint Petersburg in 1828–1830 (a fragment of a map by A.L. Mayer (http://www.etomesto.ru/map-peterburg_1828-city/)

impressiveness of the building have been lost" (Grabar, 1910)

- V.Ya. Kurbatov: "The entire facade of the Admiralty is covered with groves of the poorly planned Alexander Garden... It goes without saying that this structure that exceeds all that was made in the ancient and new world should be more visible. However, most citizens of Saint Petersburg do not have a clue about the beauty of this outstanding artwork of a Russian genius... Its effect was lost for the city when the boulevard was arranged in place of the former ditches (by L. Ruska). Monotonous rows of trees covered the beautiful building, the boulevard did not add to the adornment of the city and did not become a place for promenades (Kurbatov, 1993).

- P. N. Stolpyansky: "The enlarged garden completely covered the facade of the Admiralty, and then it sort of absorbed Senate square. The sight of the Senate and Synod buildings with the arc to the Galernaya Street ceased to amaze; those buildings and the Admiralty itself only lost due to the trees. But if a lawn with low-height bushes was laid out there, it would be a different story" (Stolpyansky, 1923).

- M.I. Roslavlev: "The building of Saint Petersburg Admiralty is the most monumental artwork of the Alexander epoch. This amazing structure has such great history that it is needless to talk about its significance in the city construction. However, the significance of vandalism shall be noted once again. The vandalism was committed by the most recent supervisors of the city development who tolerated the high-height garden on the side of the main facade and square covering by the hideous private buildings and useless alley on the side of the Neva river. I am sure that the Admiralty ensemble and details of this world-famous architectural composition will be restored in the nearest future" (Roslavlev, 1925).

Conclusions

The study performed showed that the landscape characteristics of the squares' system formed in the 1830s in the central part of Saint Petersburg around the Neva river water area were fundamentally changed during reconstructions held in the second half of the 19th – early 20th centuries. Senate, Admiralty, Rumyantsev, Collegiate squares and Razvodnaya ground near the Winter Palace lost their transparency. Visual connections between the Neva river expanses and open public spaces were disturbed or suppressed within the city center. This situation is preserved at the present time, that is why the statement that one of the architectural features of the Saint Petersburg historic center is its"single continuous open space formed by rivers and canals, squares, avenues, streets and gardens" (Shvidkovsky, 2007) should be deemed obsolete.

It should be considered that this "distortion of classical ensembles... occurred due to conscious efforts to overcome classicistic standardization", and the main means of transformation was "spreading of green areas over urban spaces" controlled by administrative authorities of the city (Kirikov, 2006).

The increase in a share of green areas could be positively evaluated but this process occurred without the consideration of the urban-planning situation, and landscape architecture considerations were neglected. During this period no palace and park ensembles similar to those that adorned the city and its suburbs in the second half of the 18th century were created. To the contrary, it was marked by significant losses in the city artistic and urban-planning potential. Dense masses of greenery blocked classical panoramas and covered unique facades — an artwork of famous architects.

At the present time, the issue is not addressed properly (as we shoud not speak ill of the past). The main document regulating ways of development and preservation of historic heritage in the city is Decree of the Government of Saint Petersburg No. 1681 "Concerning Saint Petersburg strategy on preservation of cultural heritage" dated November 01, 2005. It is clarified that in our city "cultural heritage protection items include the nature of the environment comprising the planning module of quarters and land plots, scale, height and segmentation of the development". The "unique degree of preservation regarding the Saint Petersburg historic development" is documented as well. The condition of open spaces is not considered, resulting in an illusion that the entire modern urban environment should be considered authentic. It is not clarified why the results of the "vandalistic" (Roslavlev M.I.) urban-planning activity in the late 19th – early 20th centuries do not attract any attention and should be considered as having an "integrated value as the Historic Urban Landscape".

Restitution of transparency for all Saint Petersburg squares should become a part of a concept for the prospective development of the "Historic Center of Saint Petersburg" World Heritage Site. An individual program considering individual specifics should be developed for each of them. Upon the resolution of the issue on the fate of the green areas, it is preferable to focus on the natural life cycle of plants, ensure gradual changing of landscape characteristics.

Constant care for the unique ensemble in the central part of Saint Petersburg rather than one-off events shall help the city squares to get rid of the "recent layers" (I.E. Grabar) and "recreate them in the entirety of their architectural and artistic appearance" (. Obviously, it will take some time, but Saint Petersburg is a young city with a long and splendid future ahead.

References

Batyushkov, K.P. (1978). *Opyty v stikhakh i proze VI. Progulka v Akademiyu KHudozhestv '1814 [Experiments in verse and prose VI. A walk to the Academy of Arts — 1814].* Leningrad: Nauka. (in Russian)

Benois, A.N. (1902). Zhivopisnyj Peterburg [Picturesque Petersburg]. *World of Art*, 7 (1), pp. 1–5. (in Russian)

Borisova, E.A. (1973). *Raboty, Domeniko Trezini po planirovke i zastrojke Strelki Vasil'evskogo ostrova v Peterburge [Works by Domenico Trezzini on planning and development of the Spit of Vasilyevsky Island in Saint Petersburg].* Moscow: Nauka. (in Russian)

Georgi. J.G. (2001a). *Opisanie rossijsko-imperatorskogo stolichnogo goroda Sankt-Peterburga. Zdanie Dvenadtsati kollegij [Description of the Russian Imperial capital city Saint Petersburg and the memorable sites in its suburbs, with a map. Twelve Collegia].* Available at: http://www.ipetersburg.ru/zdanie-dvenadcati-kollegiy/ (accessed on 14.05.2018) (in Russian)

Georgi, J.G. (2001b). *Opisanie rossijsko-imperatorskogo stolichnogo goroda Sankt-Peterburga [Description of the Russian Imperial capital city Saint Petersburg and the memorable sites in its suburbs, with a map].* Saint Petersburg: Adamant Media Corporation. (in Russian)

Kirichenko, E.I. (2010). *Gradostroitel'stvo Rossii serediny XIX - nachala XX stoletiya. Kniga 3. Stolitsy i provintsiya [Town planning in Russia of the mid 19th – early 20th centuries. Volume 3. Capitals and provinces].* Moscow: Progress-Traditsiya. (in Russian)

Kirikov, B.M. (2006). *Arkhitektura Peterburga kontsa XIX- nachala XX veka. Eklektika. Modern. Neoklassitsizm [Architecture of Petersburg in the late 19th – early 20th centuries. Eclecticism. Modern. Neoclassicism].* Saint Petersburg: Kolo. (in Russian)

Kurbatov, V.Ya. (1993). *Peterburg. Hudozhestvenno-istoricheskij ocherk i obzor hudozhestvennogo bogatstva stolicy [Petersburg. Artistic and historical sketch and review of the artistic wealth of the capital]*. Leningrad: Lenizdat. (in Russian)

Lisovsky, V.G. (2004). *Arkhitektura Peterburga. Tri veka istorii [Architecture of Saint Petersburg. Three centuries of history].* Saint Petersburg: AO Slaviya. (in Russian)

Nikitenko, G.Yu., Sobol, V.D. (2002). *Vasileostrovskij rajon (Entsiklopediya ulits Sankt-Peterburga) [Vasileostrovsky District (Encyclopedia of Saint Petersburg streets)].* Saint Petersburg: Beloye i Chernoye. (in Russian)

Printseva, A. (2016). *Cirk v dorevolyucionnoj Rossii [Circus in pre-revolutionary Russia].* Available at: https://arzamas.academy/mag/294-circus (accessed on: 20.05.2018)

Roslavlev, M.I. (1925). *Old Petersburg — New Leningrad. City construction in the past and future.* Leningrad: Publishing House of the Academy of Arts.

Shuysky, V.K. (1989). *Andreyan Zakharov.* Leningrad: Lenizdat. (in Russian)

Shvidkovsky, D. (2007). *Russian architecture and the West*. New Haven: Yale University Press.

Sindalovsky, N. (1997). *Stroitel'stvo Peterburga pri Petre I [Saint Petersburg construction under Peter I]*. Saint Petersburg: Norint. (in Russian)

Sindalovsky, N.A. (2012). *Legendy peterburgskikh sadov i parkov Rumyantsevskij skver [Legends of Saint Petersburg gardens and parks. Rumyantsev Garden].* Saint Petersburg: Tsentrpoligraf. (in Russian)

Sorokin, P.E., Semenov, S.A. (2003). Arkheologicheskie raskopki u zdaniya Dvenadtsati kollegij v 2000–2002 [Archaeological excavations near the Twelve Collegia in 2000–2002]. *Archaeological heritage of Saint Petersburg*, 1, pp. 124–159. (in Russian)

Stolpyansky, P.N. (1923). *Staryj Peterburg: Admiraltejskij ostrov: Sad trudyashchihsya [Old Petersburg. Admiralty Island. Labourers Garden].* Moscow: GIZ. (in Russian)

Retrospective Statement of Outstanding Universal Value "Historic Centre of Saint Petersburg and Related Groups of Monuments" (1990). Available at: http://kgiop.gov.spb.ru/media/uploads/userfiles/2015/08/24/%D0%94%D%B5%D0%BA%D0%BB%D0%B0%D1%80%D0%B0%D1%86%D0%B8%D1%8F_%D0%92%D0%A3%D0%A6.pdf (in Russian)

Zimin, I.V. (2012). *Zimnij dvorec. Lyudi i steny. Istoriya imperatorskoj rezidencii. 1762-1917 [Winter Palace. People and walls. History of the Imperial Residence. 1762 1917]*. Saint Petersburg: Centrpoligraf. (in Russian)

DESIGN OF RESIDENTIAL COMPLEXES WITH ACCOUNT FOR CLIMATIC FACTORS

Elena Moshninova[1], Natalia Novokhodskaia[2]

[1,2] Saint Petersburg State University of Architecture and Civil Engineering
2-ya Krasnoarmeiskaya st., 4, St. Petersburg, Russia

[1] lira0lights@gmail.com

Abstract

The article addresses an issue of designing and selling residential complexes without account for climatic characteristics of the territory. Main climatic factors affecting the urban environment, that shall be taken into account in design and construction, are considered. The article gives definitions to climate, climatic factors, local climatic factors, and windproof buildings. The state of the problem is studied, architectural and planning features regarding design of residential complexes exposed to the wind current in hot dry climate conditions are identified and analyzed, recommendations on design of the residential environment considering the above climatic factors are given.

Keywords

Residential complex, block, inner-block environment, climate, climatic factors, windproof buildings.

Introduction

Architecture has always been an integral part of human life. Houses have become one of the main means of people's protection against the unfavorable environment; with their help people transform the space around, trying to create the most convenient and safest living environment.

The Russian Federation has an extensive variety of natural and climatic conditions. Construction technologies and architectural and planning solutions acceptable for one region of the country can be completely unsuitable for life in another region. This trend can be analyzed by studying standard design solutions used in the territory of Russia and CIS countries during the Soviet period. In the Soviet times, large-scale residential construction was based on standard design solutions used for entire geographic regions. Standard projects were often developed without account for local climatic factors and the existing urban development directly affecting such local climatic factors, in particular, the wind direction and wind strength. The idea of regional typification of buildings was proposed back in the Soviet era, and despite the attempts of individual creative teams to start the development of such projects, it was not supported. One of the problems was the absence of a well-developed theoretical framework that would determine design methods for certain climatic conditions.

Nowadays, when performing design tasks, architects and representatives of related trades consider the area climate mainly with regard to the choice of a construction system and construction materials that should withstand wind and snow loads, precipitation, temperature fluctuations, etc. The climate should be considered not only in the selection of structures and construction materials, but also with regard to its influence on the urban development pattern, orientation and height of buildings. It also should be reflected in architectural and planning solutions as climatic factors directly affect the building operation. Based on the climatic factors of the territory, it is possible to create a unique architectural appearance, appropriate to the climatic zone and specific territory. Even our ancestors learned from their own experience and

DOI: 10.23968/2500-0055-2018-3-3-22-28

mistakes to adapt their houses to climate conditions, and select means of their protection against the unfavorable environment, which subsequently led to the formation of certain building archetypes and established the national identity of architecture in particular areas.

Climatic factors and their influence on the residential environment of blocks

The issue of climate impact on houses has interested many generations of architects. The concept of climate refers to the long-term weather pattern typical for a particular territory (Neklyukova, 2010). Just like the weather, the climate depends on the geographical latitude determining the amount of solar radiation coming to the earth's surface, altitude above the sea level, presence of water reservoirs, nature of the underlying surface, ground relief, nature of air masses and atmospheric fronts movement, i.e. on numerous climatic factors. Climatic factors (hereinafter referred to as CFs) are conditions that determine the climate of the territory. Disregarding climatic factors adversely affects the development of modern architecture, hinders the establishment of comfortable microclimate in premises, increases heat losses of buildings. CFs typical for the territory of one small city, settlement, or district are called local CFs and characterized by the air temperature (average annual, January and July temperatures), amount and type of precipitation, prevailing wind directions (Petrova, 2016), amount of solar radiation coming to the surface, water supply, dust/wind transfer, ground relief (in particular, angles of slopes and orientation to cardinal directions), development pattern, extent and pattern of green areas (Litskevich, 1984), seismic activity, etc.

One of the important microclimate factors undergoing significant changes under the influence of urban development and having a strong effect on the urban environment and residential buildings is wind. The irrational orientation of buildings, lack of consideration of the prevailing winds create areas of accumulating and increasing wind currents that adversely affect building constructions, create wind corridors in the urban space, and, therefore, adversely affect the living environment. Besides, a combination of wind with other CFs is also of great importance. Shortage or surplus of solar radiation, impact of strong wind and absence of wind currents have a significant adverse effect on the microclimate in premises and inner-block spaces. If low wind speed can be useful (for through ventilation of premises), especially for hot climatic zones, strong winds can cause significant damage to building structures, facings and internal courtyard spaces, and, therefore, adversely affect the life of people.

During the Soviet era, data were collected on the basis of already implemented projects. Territories were analyzed, data on the climate, on the effect of wind on urban development and on the microclimate environment of blocks were collected, wind behavior in the residential environment of blocks was investigated, methods of protection, as well as ways of regulating and reducing the wind current speed were proposed. The studies conducted were devoted to the conditions of the Far North, as well as the central part of the country, where low temperatures in combination with winds as well as snow/wind transfers were the main factors. Temperature fluctuations in the courtyard spaces, depending on the width of courtyards and passages, angle of sunlight incidence, changes in

Beaufort number	Wind description	Sea and land conditions	Wind speed, m/s
0	Calm	Smoke rises vertically	0.3
1	Light air	Direction shown by smoke drift but not by wind vanes	0.6–1.7
2	Light breeze	Wind felt on face; leaves rustle; wind vane moved by wind..	1.8–3.3
3	Gentle breeze	Leaves in constant motion; light flags extended	3.4–5.2
4	Moderate breeze	Wind raises dust and loose paper. Small branches moved	5.3–7.4
5	Fresh breeze	Small trees in leaf begin to sway	7.5–9.8
6	Strong breeze	Large branches in motion; whistling heard in telegraph wires	9.9–12.4
7	High wind, near gale	Whole trees in motion...	12.5–15.2
8	Gale	Twigs break off trees; generally impedes progress..	15.3–18.2
9	Strong gale	Slight structural damage (chimney pots removed)	18.3–21.5
10	Storm	Trees uprooted; considerable structural damage..	21.6–25.4
11	Violent storm	Very rarely experienced; accompanied by widespread damage	25.5–29.2
12	Hurricane force		More than 29.3

Figure 1. The Beaufort Scale

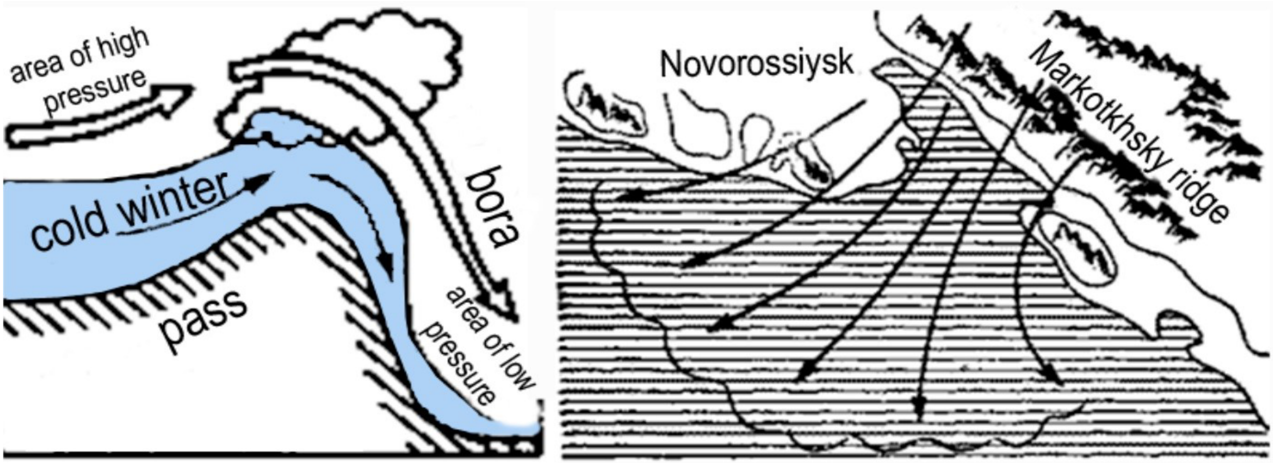


Figure 2. A diagram of bora occurrence

local factors under the influence of urban development, as well as their impact on health and well-being of settlement inhabitants were analyzed. As a result, the collection of such data took several decades.

Strong winds with a hot dry climate represent a rare combination of local CFs. As it was mentioned above, the adverse effect of wind on the residential environment in our country is often associated with negative temperatures (thermal effects) and blizzards. The most unfavorable combinations of temperatures and wind speeds are as follows: -30ºC and 1.5 m/s, -25ºC and 2 m/s, -15ºC and 3.5 m/s, as well as 5 m/s and higher at any temperature (Pivkin, 1971). Moreover, wind can have not only thermal, but also dynamic effect (Penwarden, 1975). Dynamic effects are perceived at a wind speed of more than 5 m/s. (Nikolopoulou, 2002). Wind speeds from 12.5 to 15.2 m/s are classified as "high wind" ("near gale") according to the Beaufort scale (Figure 1), when progress is impeded. Winds stronger than 15.3 m/s are classified as gale, strong gale, storm and violet storm, when chimneys fall, trees are uprooted; at the wind speed of 25 m/s widespread damage is observed. Wind speeds over 29.3 m/s are classified as a "hurricane force" (Aronin, 1958).

Here it is worth mentioning a unique natural phenomenon called "bora" or "north-eastern wind" which is a strong cold gusty wind blowing mainly during the cold season (approximately from November to March) down the mountain slopes and bringing a considerable temperature drop (a temperature drop of 15ºC degrees was recorded). It is observed in areas where a low mountain range borders on a warm sea (Figure 2). Violent bora winds can be felt in Italy (Trieste), Croatia (Rijeka, Zadar, Senj), and France. In the territory of the Russian Federation, this phenomenon is observed near the coasts of Lake Baikal, the city of Pevek, as well as in Novorossiysk (Tsemes bay; it also affects the Gelendzhik Bay), where the "north-eastern wind" became a landmark of the city (speed of the main wind current is about 45 m/s with gusts up to 70 m/s). Novorossiysk, Trieste, Rijeka, etc. have similar climatic factors: the presence of a warm sea, average minimum temperatures not lower than 2.7ºC, average summer temperatures equal to about 27.4/28.1ºC. Thus, upon design of residential blocks in the territories considered, repetitive hurricane winds (with their average duration in Novorossiysk of 50 days per year) in winter and a hot dry climate in summer shall be taken into account in urban planning and architectural solutions for residential complexes.

The main means of protecting the inner-block environment against strong winds are windproof screens which are usually represented by windproof buildings, as well as green windbreaks. A windproof building is a long windscreen building located on the border of a residential territory, protecting it against unfavorable winds. One of the most frequently used solutions is the arrangement of green areas (Figure 3). Such areas are considered efficient if they consist of 2–3 rows with a 40–50% clearance: in this case it is possible to reduce the wind speed by 50–80%.

In the course of field studies, as well as studies using the wind tunnel to test residential blocks, it was determined that windproof buildings located perpendicular to the direction of the prevailing wind current are subject to significant turbulence of the air current, gustiness of the flow; they also experience supercooling in winter and overheating in

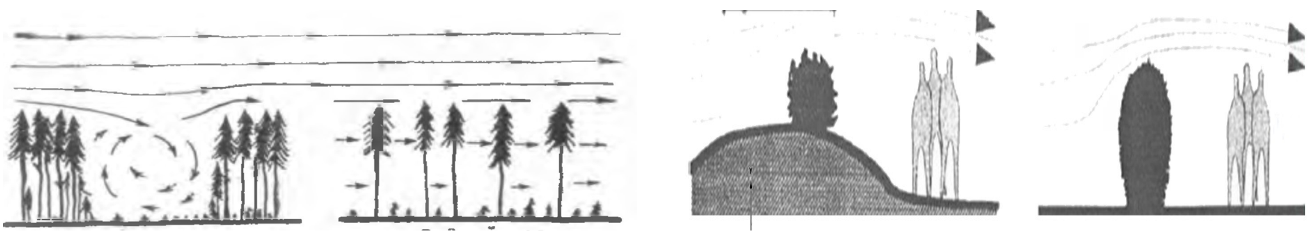


Figure 3. Wind movement on a cleared forest site and in a sparse forest

DOI: 10.23968/2500-0055-2018-3-3-22-28

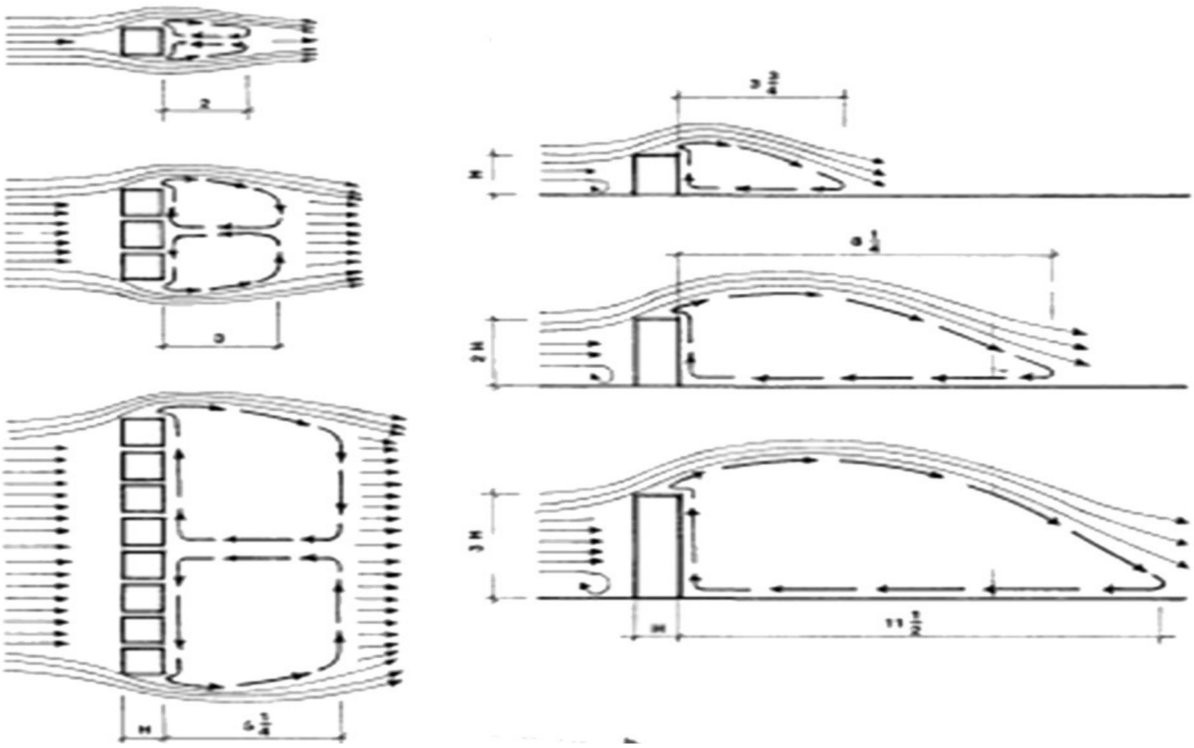


Figure 4. The wind shadow of buildings, depending on the length and height of the windproof building.

summer, if we speak about premises facing the windward side. It is possible to reduce the wind speed by about 40% (Pivkin, 1971). Heat losses of buildings due to wind cooling make up 20% of total heat losses (Litskevich, 1984). Such problems can be solved by bilateral orientation of apartments, ensuring the equalization of temperatures in premises facing the windward and downwind sides, as well as by such engineering solutions as triple glazing, air conditioning, arrangement of blinds, etc.

After a wind current passes a windproof building, at a distance equal to four heights of the building (4h), wind vortices and reverse currents form and descend to the inner-block environment (Figure 4). To eliminate this phenomenon, it is necessary to take windproof measures of the "second" order, i.e. to stipulate for rows of wind-blocking trees or a building at a distance of 2h/3h from the first building. The angle of building orientation relative to the prevailing winds as well as residential groups (usually perpendicular to the wind current or with a deflection of 20/30 degrees) plays a significant role. The wind shadow of a building also depends on the building shape and height: the narrower, the taller and the higher the building is, the larger the wind shadow it casts, therefore, it is better from the windproof point of view (Pivkin, 1971). We also should not forget about strong upward wind currents created near high-rise and excess height buildings as these currents adversely affect the residential environment of blocks (Litskevich, 1984).

Groups of buildings were analyzed by scientists and some aerodynamic effects describing the influence of the building location on the formation of air currents were identified. One of such phenomena is the "effect of a horizontally located building," where an air current colliding with a horizontally located building is thrown over the building, descending into the internal courtyard space at an angle of about 45ºC, thus forming wind vortices. "The effect of passages under high-rise buildings" resides in behavior of wind currents in through passages connecting

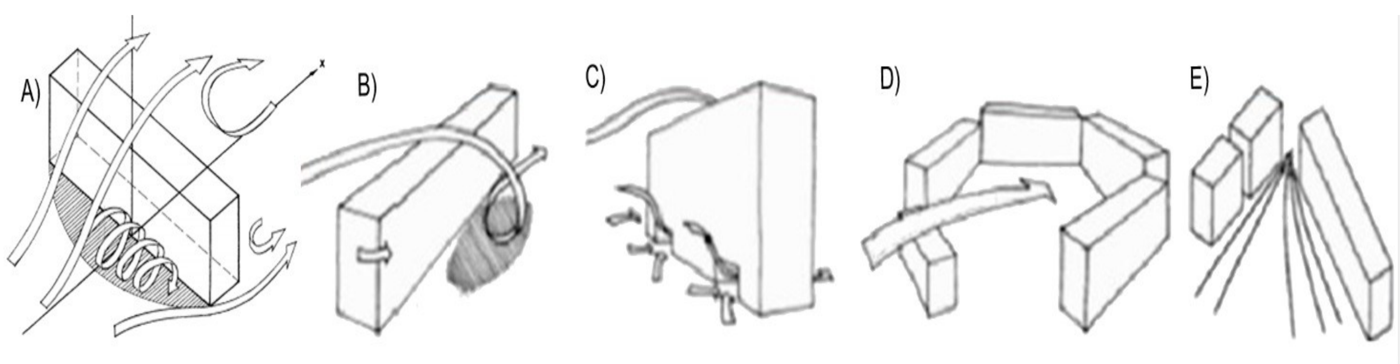


Figure 5. Aerodynamic wind effects: A) distribution of vortices on the windward side of the building, B) the effect of a horizontally located building, C) the effect of passages under high-rise buildings, D) the cell effect, E) the Venturi flue effect

the windward and downwind sides of buildings. On the opposite sides of a building, different levels of pressure form, wind moves from the high-pressure area to the low-pressure area, causing an increase in the wind speed in passages. Moreover, it has been revealed that as the number of floors increases, the pressure difference increases as well (the higher the building is, the less favorable passage it has). The "Venturi effect" or "flue effect" is quite common: it is generated by buildings forming an angle or a narrowing passage in the direction of the wind current (Jedid, 2016). The wind current grows stronger in the narrowing area of the passage (Figure 5). In a hot climate, this effect is used to enhance the existing wind current and pull it into the internal courtyard space.

In the course field microclimatic observations, it has been established that perimetral (closed) development is more preferable for winter conditions (adverse wind effect), and ribbon development is more preferable for summer conditions (Pivkin, 1971). Based on this, it can be concluded that the optimal solution for territories with strong winds and a hot dry climate will be a mixed block structure combining semi-closed development involving windproof buildings on the windward side and ribbon development on the downwind side of the block (Figures 6, 7).

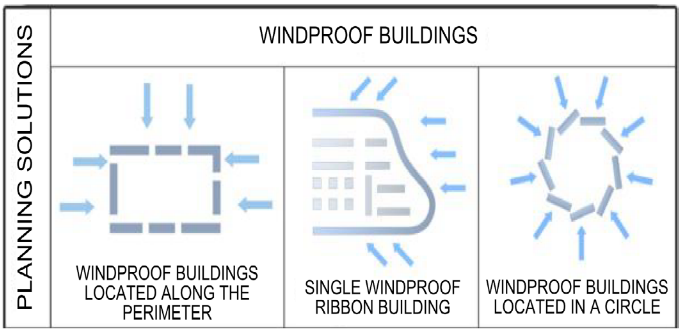


Figure 6. Urban-planning solutions for blocks of windproof buildings. An adverse wind effect

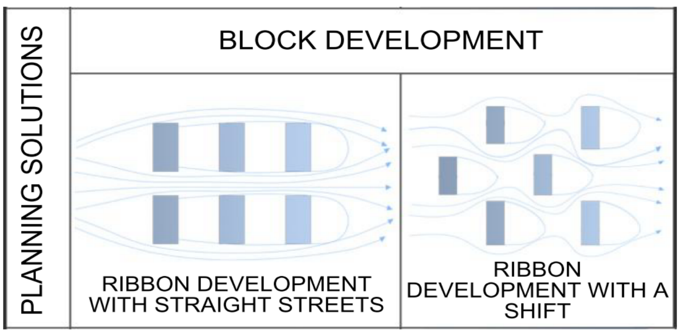


Figure 7. Urban-planning solutions for blocks in areas with favorable winds

Countries with a hot dry climate often consider wind protection in combination with protection against sands ("dust/wind transfer"). The following architectural and urban-planning solutions are typical for territories with a hot dry climate (significant overheating in summer at low humidity): closed nature of building operation, dense development, narrow corridors of streets create shaded passages (the ratio of the height of buildings to the width between them is more than 1). Canopies, protruding overhangs, brise-soleils (Bairamova, 2017), stationary or mobile sun protection structures (blinds, fins, etc.) are widespread. Artificial cooling of premises is used, natural ventilation is organized without lowering of the required level of moisture content; air permeability, heat protection are ensured. In order to provide natural ventilation, apartments are located on both sides of residential buildings. In a hot climate, a low wind speed is favorable, since such wind cools surfaces, therefore, premises and passages between courtyards are oriented in such a way as to catch a favorable wind current, and sometimes buildings are arranged above the ground on pylons, which provides additional shading and pulls wind into the courtyards.

Results and Discussion

It is necessary not only to adapt to the climate, especially to its physical effects on the living organism, but also benefit from climatic factors affecting a particular territory. Considering basic climatic factors of the territory, it is possible to create rational spaces needed for human activity, e.g. install wind generators in areas with constant favorable winds, as well as ensure through ventilation of premises, install solar batteries in southern regions of the country where clear, sunny weather prevails and there is a large amount of solar radiation.

Despite the development and growth of cities, the relationship between nature and man is indissoluble. At the present time, the emergence and development of new technologies, high pace of construction pose new challenges before architects, including an important problem of linking nature and climate with architecture.

Thus, the relevance of the topic is due, on the one hand, to the current urban-planning and architectural practice in Russian cities (not based on individual climatic conditions of specific regions) and, on the other hand, to the growing needs of society in the formation of an environmentally sustainable and comfortable environment that would meet the specific natural conditions.

Conclusions

The search for the optimal solution for the interconnection of climatic factors is carried out in a specific territory with account for the wind rose (directions of hurricane winds (bora winds) and favorable winds' movement), geographical location (angle of sunlight incidence). Significant adjustments can be made due to the inclusion of additional factors such as ground relief, seismic activity, etc.

Thus, during the analysis of climatic conditions, where the combination of unfavorable winds in winter and a hot dry climate in summer has a significant influence, we have obtained the requirements that, in fact, contradict each other:

1. windproof buildings and the following rows of buildings shall be located perpendicularly or with a

DOI: 10.23968/2500-0055-2018-3-3-22-28

deflection of 20/30 degrees from the main wind current (wind protection);

2. residential premises, courtyard spaces and pedestrian paths shall be oriented along the main wind current (protection against overheating).

However, we can distinguish several common features as well:

- premises' orientation to both sides of the building;
- provision of natural ventilation;
- a need for heat protection of buildings: in one case, against heat, and in another — against cooling by wind;
- a closed structure of courtyard spaces, protecting, in one case, against descending wind vortices and wind speed increase, and in another — against excessive insolation, hot wind and sand.

References

Aronin, J.E. (1958). *Climate and architecture. Progressive architecture book*. Moscow: Gostroyizdat.

Bairamova, J. (2017). *Arkhitekturnoe formirovanie kul'turno-turisticheskikh kompleksov v istoricheskoj srede Turkmenistana [Architectural formation of cultural and tourist complexes in the historical environment of Turkmenistan]*. PhD Thesis in Architecture. Moscow: Moscow Institute of Architecture. (in Russian)

Jedid, M. (2016). *Arkhitekturnaya morfologiya i teplovoj komfort otkrytykh obshhestvennykh prostranstv v usloviyakh zasushlivogo klimata [Architectural morphology and thermal comfort of open public spaces under the conditions of dry climate].* PhD Thesis in Architecture. Nizhny Novgorod: Nizhny Novgorod State University of Architecture and Civil Engineering. (in Russian)

Krasheninnikov, A. (2005). *Gradostroitel'noe razvitie zhiloj zastrojki. Issledovaniya opyta zapadnykh stran [Urban-planning development of residential buildings. Studies of the Experience of Western countries].* Moscow: Arkhitektura-S. (in Russian)

Litskevich, V. (1984). *Zhilishha i klimat [Residential buildings and climate].* Moscow: Stroyizdat. (in Russian)

Litskevich, V. (1975). *Uchet klimaticheskikh uslovij pri proektirovanii zdanij v razlichnykh rajonakh SSSR [Considering climatic conditions in design of buildings in various regions of the USSR].* Moscow: Stroyizdat. (in Russian)

Neklyukova, N. (2010). *Geografiya: spravochnik dlya starsheklassnikov i postupayushhikh v vuzy [Geography. Reference book for high school students and prospective university students]*. Moscow: AST-PRESS SHKOLA. (in Russian)

Nikolopoulou, M. (2002). *Designing open spaces in the urban environment: a bioclimatic approach.* RUROS, Greece. Available at: http://alpha.cres.gr/ruros/dg_fr.pdf (accessed on: 30.06.2018) (in French)

Penwarden, A.D., Wise, A.F.E. (1975). *Wind environment around buildings*. London: Dept. of the Environment, Building Research Establishment: H. M. Stationery Off.

Petrova, Z.K. (2016). *Organizatsiya maloehtazhnoj zhiloj zastrojki v sisteme rasseleniya Rossii [Low-rise residential development in the settlement system of Russia].* DSc Thesis in Architecture. Moscow: Central Research and Design Institute of Residential and Public Buildings of the Ministry of Construction, Housing and Utilities of the Russian Federation. (in Russian)

Petrova, Z. (1980). *Mnogoehtazhnye koridornye zhilye doma [Multi-story corridor residential buildings].* Moscow: Stroyizdat. (in Russian)

Pivkin, V. (1971). Vetrozashhitnye meropriyatiya v planirovke i zastrojke naselennykh mest srednej polosy Sibiri [Wind protection measures in planning and development of inhabited localities in the central part of Siberia]. *Budivelnik*, 7, pp. 35–43. (in Russian)

DOI: 10.23968/2500-0055-2018-3-3-29-41

PRACTICAL CALCULATION OF FLEXIBLE MEMBERS WITH THE USE OF NON-LINEAR DEFORMATION MODEL AS EXEMPLIFIED BY TYPICAL GIRDER RGD 4.56-90

Eres Opbul[1], Dmitrii Dmitriev[2], Phan Van Phuc[1,3]

[1] Saint Petersburg State University of Architecture and Civil Engineering
2-ya Krasnoarmeiskaya st., 4, St. Petersburg, Russia

[2] "TEKTON-SPB" LLC
Oktyabrskaya nab., 104, St. Petersburg, Russia

[3] Vinh University
182 Le Duan, Ben Thuy, Vinh City, Vietnam

[1] phucprodhv@gmail.com

Abstract

The article is devoted to practical calculation of strength of flexible members made on the basis of non-linear deformation model taking into account experimental diagrams of materials deformation. The relative deformations are determined in the proposed calculation depending on maximum flexion of a member. The calculation of maximum flexion of a member will be performed using two iteration methods. The basic calculation formula, original block diagrams of methods and comparison of calculation parameters proceeding from results of practical calculations made as exemplified by typical girder are provided.

Keywords

Deformation model, non-linear calculation, deformation diagram, iteration, stiffness matrix, stress diagram, neutral line, reinforcement.

Introduction

Obviously, the calculation of construction structures with the use of non-linear deformation model (NLDM) qualifies as check-and-control or testing method. In this case the calculation according to NLDM will be performed with definite force (external or internal) values, reinforcement (of concrete) and member geometrical dimensions (Boujelben, Ibrahimbegovic, 2017; Jagtap et al., 2018).

This article presents two methods of iteration calculations. The purpose of iteration process consists in determining maximum flexion of a member and location of relative deformations in target points of sections depending on the target flexure (Patni, 2018; Mao, Zhang, 2018).

The target flexure is determined in the first method with finding a new position of neutral line, in the second method it depends on the matrix of stiffening behavior of every small area.

The first iteration method of calculation with respect to steel fiber reinforced-concrete structures has been described in the works (Morozov, Opbul, 2016; Opbul et al., 2017). Described below is the second method of non-linear calculation with due account of paragraphs 8.1.20-8.1.29, 3.72-3.75 given in standards (TsRIIPromzdaniy OJSC, 2005; Minstroy RF, 2013) (In order to contract the volume of article, the first three and the last (eleventh) iterations of calculations only are given).

Diagrams of materials deformation

A typical girder RGD 4.56-90: concrete B40, reinforcement A400 are being considered. Ref. Fig. 3 for girder geometrical dimensions and reinforcement.

The calculation formulae have been acquired according to (TsRIIPromzdaniy OJSC, 2005; Minstroy RF, 2013) and shown in Fig. 1, 2 to determine stresses and stress-strain moduli.

Judgments and assumptions: plane sections hypothesis is true; for determining center of gravity of the given girder cross-section and for the first method of iteration calculation the girder material works in the elastic stage (there are no cracks, the moduli of small areas equal the initial modulus of elasticity).

a) Calculation formulae of stresses and moduli for concrete of class B40

In case of concrete compression:

- $0 < \varepsilon_{bi} < 150 \cdot 10^{-5}$: $\sigma_{bi} = R_b \cdot \dfrac{\varepsilon_{bi}}{150 \cdot 10^{-5}}$ MPa;

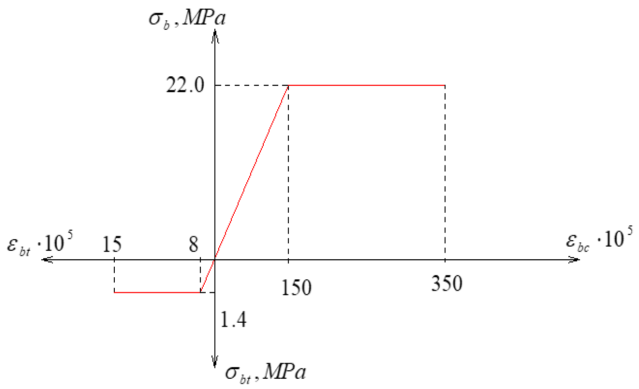


Figure 1. Diagram of Concrete Condition

$$E'_{bi} = const = \frac{R_b}{150 \cdot 10^{-5}} = 14666.7 \text{ MPa}$$

- $150 \cdot 10^{-5} < \varepsilon_{bi} < 350 \cdot 10^{-5}$: $\sigma_{bi} = R_b = 22$ MPa;

$$E'_{bi} = \frac{R_b}{\varepsilon_{bi}} = \frac{22}{\varepsilon_{bi}} \text{ MPa}$$

In case of concrete expansion:

- $0 < \varepsilon_{bti} < 8 \cdot 10^{-5}$: $\sigma_{bti} = R_{bt} \cdot \dfrac{\varepsilon_{bti}}{8 \cdot 10^{-5}}$;

$$E'_{bti} = \frac{R_{bt}}{8 \cdot 10^{-5}} = \frac{1.4}{8 \cdot 10^{-5}} = 17500 \text{ MPA}$$

- $8 \cdot 10^{-5} < \varepsilon_{bti} < 15 \cdot 10^{-5}$: $\sigma_{bti} = R_{bt} = 1.4$ MPa;

$$E'_{bti} = \frac{1.4}{\varepsilon_{bti}} \text{ MPa}$$

b) *Calculation formula of stresses and moduli for reinforcement in case of expansion and contraction*:

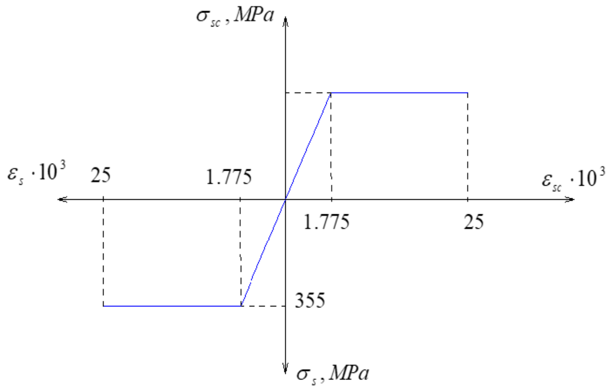


Figure 2. Diagram of Reinforcement Condition

- $0 < \varepsilon_{si} < 1.775 \cdot 10^{-3}$: $\sigma_{si} = R_s \cdot \dfrac{\varepsilon_{si}}{\varepsilon_{s1}} = 355 \cdot \dfrac{\varepsilon_{si}}{1.775 \cdot 10^{-3}}$ MPa,

where $\varepsilon_{s1} = \dfrac{R_s}{E_s} = \dfrac{355}{2 \cdot 10^5} = 1.775 \cdot 10^{-3}$ $E'_s = E_s$

- $1.775 \cdot 10^{-3} < \varepsilon_{si} < 25 \cdot 10^{-3}$: $\sigma_{si} = R_s = 355$ MPa,

$$E'_s = \frac{R_s}{\varepsilon_{si}} = \frac{355}{\varepsilon_{si}}, \text{MPa}$$

Basic calculation formulae and block diagram of the first method

A) Center of gravity of a given cross section:

$$y_0 = \frac{S_{red}}{A_{red}} \quad (1)$$

B) Reduced static moment:

$$S_{red} = \sum A_{bi} y_{bi} + \sum \alpha \cdot A_{si} y_{si}, \quad (2)$$

where A_{bi}, A_{si} - area of section of *i*-n small area (layer) of concrete and *i*-n reinforcement, accordingly; y_{bi}, y_{si}- distances from extreme stretched fiber, accordingly, to the center of gravity of *i*-n small area of concrete and *i*-n reinforcement, *α* - modular ratio of reinforcement into concrete.

C) Reduced cross-section area:

$$A_{red} = \sum b_{bi} \cdot \Delta_{bi} + \sum \alpha \cdot A_{si}, \quad (3)$$

where $b_{bi,}$ Δ_{bi} - width and height (thickness) of *i*-n concrete small area, accordingly.

D) New position of neutral line (NL):

$$y_{0j} = \frac{\sum E'_{bi} A_{bi} y_{bi} + \sum E'_{si} A_{si} y_{si}}{\sum E'_{bi} A_{bi} + \sum E'_{si} A_{si}}, \quad (4)$$

where, E'_{bi}, E'_{si} - moduli of concrete and reinforcement deformation.

E) Member flexure:

$$\frac{1}{r_j} = \frac{M}{EI_{red}} = \frac{M}{\sum E'_{bi} A_{bi} \left(y'_{bi}\right)^2 + \sum E'_{si} A_{si} \left(y'_{si}\right)^2}, \quad (5)$$

DOI: 10.23968/2500-0055-2018-3-3-29-41

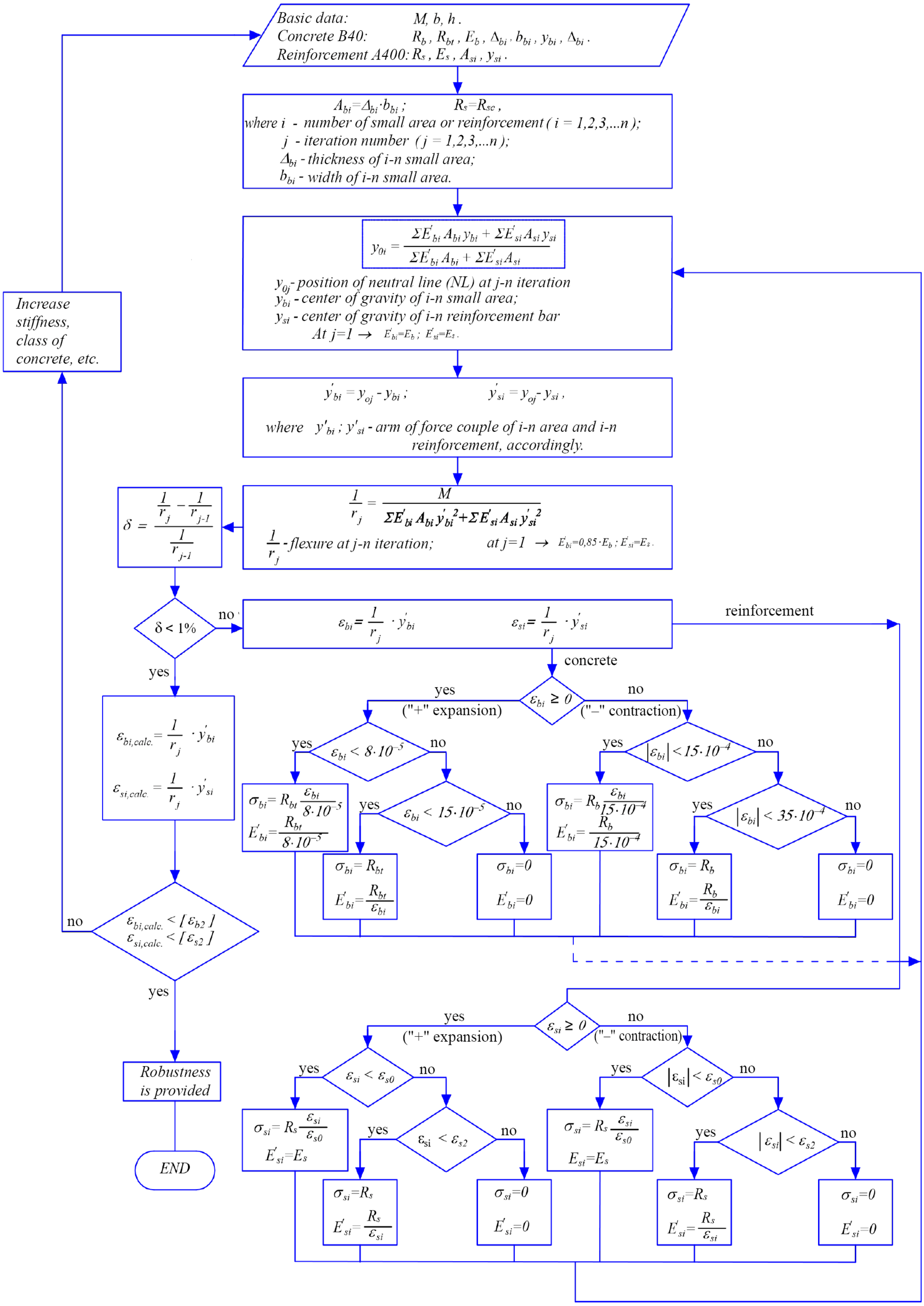


Figure 3. Block Diagram of the First Method

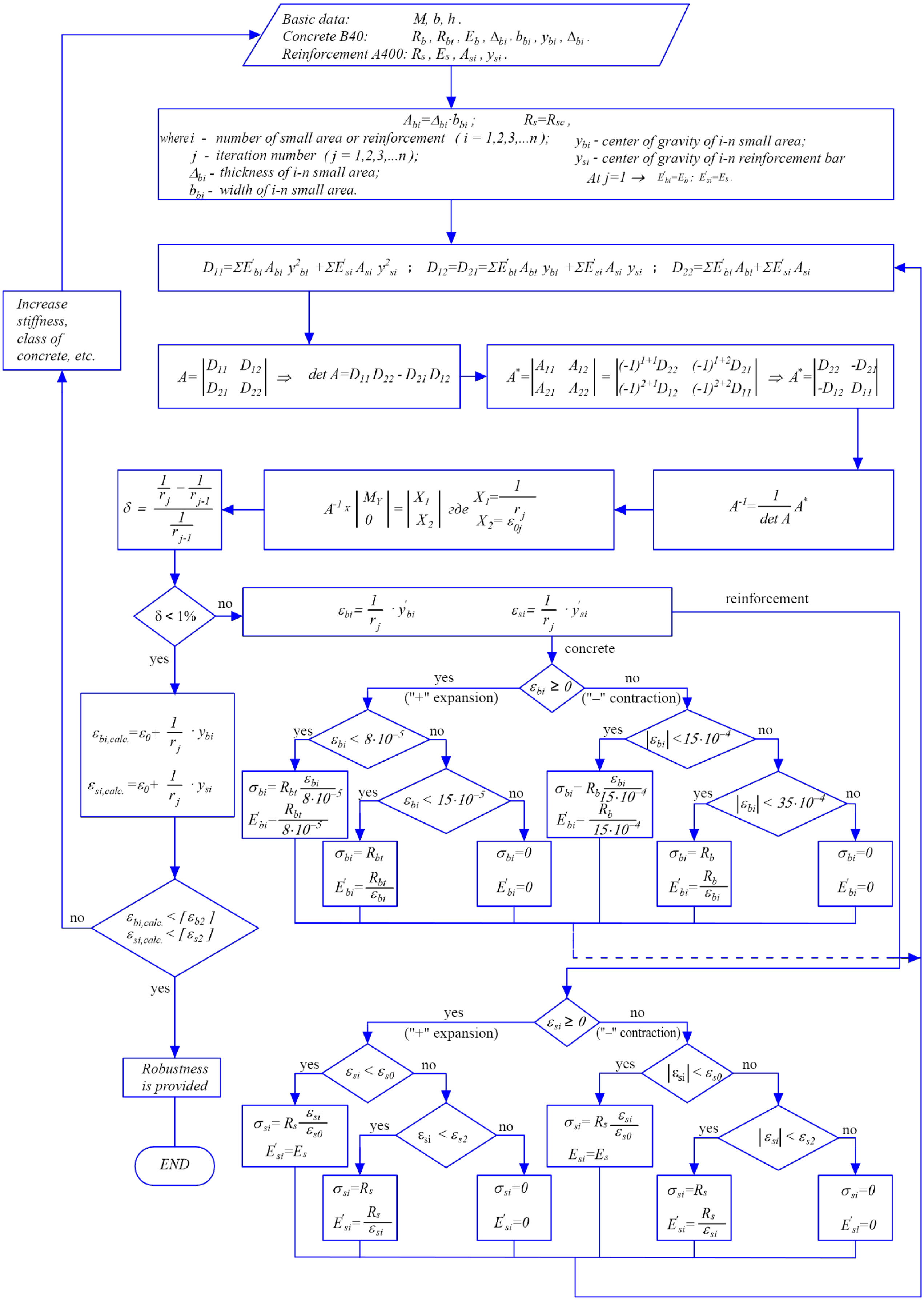


Figure 4. Block Diagram of the Second Iteration Method

DOI: 10.23968/2500-0055-2018-3-3-29-41

where, $y'_{bi} = y_{0j} - y_{bi}$, $y'_{si} = y_{0j} - y_{si}$ - arm of force couple for small areas of concrete and reinforcement, accordingly.

F) Condition when the maximum design flexure occurs $\frac{1}{r_{j,calc}}$:

$$\delta = \frac{\frac{1}{r_j} - \frac{1}{r_{j-1}}}{\frac{1}{r_{j-1}}} \cdot 100\% \le 1\% \quad (6)$$

G) Deformations

$$\varepsilon_{bi} = \frac{1}{r_j} \cdot y'_{bi};\ \varepsilon_{si} = \frac{1}{r_j} \cdot y'_{si} \quad (7)$$

H) Condition of strength, when compliance is necessary:

- with respect to deformations:

$$\varepsilon_{bi,calc} < [\varepsilon_{b2}];\ \varepsilon_{si,calc} < [\varepsilon_{s2}], \quad (8)$$

where $\varepsilon_{bi,calc} = \frac{1}{r_{j,calc}} \cdot y'_{bi}$, $\varepsilon_{si,calc} = \frac{1}{r_{j,calc}} \cdot y'_{si}$ - design deformations; $[\varepsilon_{b2}]$, $[\varepsilon_{s2}]$ - permissible deformations according to [1].

- with respect to forces according to formula 3.144:

$$M_{calc} = \sum \sigma_{bi} A_{bi} y'_{bi} + \sum \sigma_{si} A_{si} y'_{si} \ge M_{ult} \quad (9)$$

Figure 3 shows an original block diagram of the first calculation method acquired in the way of iteration.

Calculation Formulae and Block Diagram of the Second Method

A) We use calculation equation 8.26÷8.52 (Morozov, Opbul, 2016), where three stiffness characteristics only get defined in case of pure flexure:

$$\begin{cases} D_{11} = \sum_i E'_{bi} A_{bi} (y'_{bi})^2 + \sum_i E'_{si} A_{si} (y'_{si})^2 \\ D_{13} = D_{31} = \sum_i E'_{bi} A_{bi} y'_{bi} + \sum_i E'_{si} A_{si} y'_{si} \\ D_{33} = \sum_i E'_{bi} A_{bi} + \sum_i E'_{si} A_{si} \end{cases} \quad (10)$$

B) Further, matrix determinant (det A) of $A = \begin{vmatrix} D_{11} & D_{13} \\ D_{31} & D_{33} \end{vmatrix}$ type will be defined, wherefrom:

$$\det A = D_{11} \cdot D_{33} - D_{31} \cdot D_{13} \quad (11)$$

Inverse matrix $A^{-1} = \frac{1}{\det A} \times A^*$, (12)

where $A^* = \begin{vmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{vmatrix}$ matrix of cofactors equal to:

$$\begin{aligned} A_{11} &= (-1)^{1+1} \times D_{33} = D_{33} \\ A_{12} &= (-1)^{1+2} \times D_{31} = -D_{31} \\ A_{21} &= (-1)^{2+1} \times D_{13} = -D_{13} \\ A_{22} &= (-1)^{2+2} \times D_{11} = D_{11} \end{aligned} \quad (13)$$

C) Product of matrices gets calculated in the form of:

$$A^{-1} \times \begin{vmatrix} M \\ 0 \end{vmatrix} = \begin{vmatrix} x_1 \\ x_2 \end{vmatrix}, \quad (14)$$

where $x_1 = \frac{1}{\rho_j}$; $x_2 = \varepsilon_0$ (15)

D) Relative deformations in concrete and reinforcement get determined according to formulae 8.29, 8.30 [1] taking into account formulae (16):

$$\begin{aligned} \varepsilon_{bi} &= \varepsilon_0 + \frac{1}{\rho_j} \cdot y'_{bi} \\ \varepsilon_{si} &= \varepsilon_0 + \frac{1}{\rho_j} \cdot y'_{si} \end{aligned} \quad (16)$$

E) Strength condition:

- with respect to deformations – ref. formula (8).
- with respect to forces according to formula 3.144 [2]:

$$M_{calc} = \sum \sigma_{bi} A_{bi} y_{bi} + \sum \sigma_{si} A_{si} y_{si} \ge M_{ult} \quad (17)$$

Figure 4 shows an original block diagram of the second iteration method.

Determining girder load-carrying ability

Basic data:

Class of concrete B40:

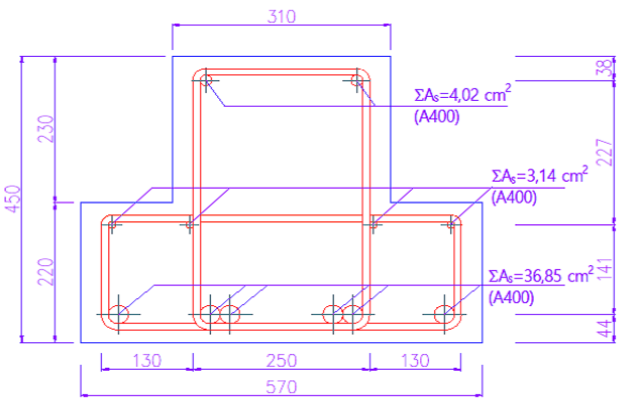


Figure 5. Girder Transversal Section

$R_b = 22MPa; R_{bt} = 1.4MPa; \quad E_b = 36000MPa$.

Longitudinal reinforcement of class A-III:

$R_s = 355MPa; R_{sc} = 355MPa; \quad E_s = 2 \cdot 10^5 MPa$.

Transversal section of 570x450 mm, girder length of 5,400 mm (Fig. 5).

Height of compressed zone:

$$x = \frac{R_s(A_{s1} + A_{s2} - A_{s3})}{R_b b} = \frac{355 \cdot (3685 + 314 - 402)}{22 \cdot 310} = 187 \text{ mm}$$

Position of the center of gravity of compressed zone:

$$y_x = \frac{b \cdot \frac{x^2}{2} + \alpha \cdot A_{s3} \cdot a_s'}{b \cdot x + \alpha \cdot A_s} = \frac{310 \cdot \frac{187^2}{2} + 5.26 \cdot 402 \cdot 38}{310 \cdot 187 + 5.26 \cdot 402} = 92 \text{ mm}$$

Design load-carrying ability:

$$M_{ult} = R_s\left[A_{s1}(h_0 - y_x) + A_{s2}(h_0 - y_x - 141)\right] =$$

$$= 355 \cdot \left[3685 \cdot (406 - 92) + 314 \cdot (406 - 92 - 141)\right] = 430 \cdot 10^6 \text{ N m}$$

Breakdown of transversal section to small areas and finding the center of gravity of every area

In order to calculate the transversal section of a member, we break it down randomly into small areas (Fig. 6). We have thirteen small areas for our example. The numbering of areas begins from the lower stretched cross-section zone.

Table 1 gives: *i* - order number of small area; $\Delta_{bi}, y_{bi}, b_{bi}, A_{bi}$ - height, distance from extreme fiber of the lower stretched zone to the center of gravity, width and area of *i*-n small area of concrete, accordingly; $E_{bi}' = 0.85E_b$ - modulus of concrete deformation; $y_{si}, A_{si}, E_{si}' = E_s$ - accordingly, distance from extreme fiber

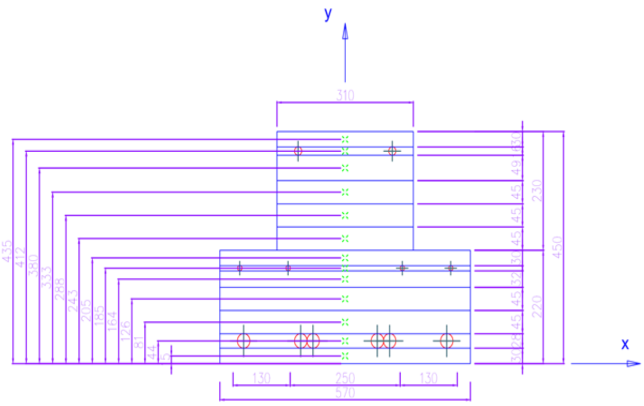


Figure 6. Breakdown of Transversal Section

Example of calculation according to the first iteration method

Table 1. Design parameters of small areas

i	Δ_{bi}	y_{bi}	b_{bi}	A_{bi}	E'_{bi}	y_{si}	A_{si}	E'_{si}	y_{oj}
	cm	cm	cm	cm^2	MPa	cm	cm^2	MPa	cm
1	3	1,5	57	171	3,06E+04				
2	2,8	4,4	57	122,8	3,06E+04	4,4	36,8	2,E+05	
3	4,5	8,05	57	256,5	3,06E+04				
4	4,5	12,55	57	256,5	3,06E+04				
5	3,2	16,4	57	182,4	3,06E+04				
6	1	18,5	57	53,86	3,06E+04	18,5	3,14	2,E+05	
7	3	20,5	57	171	3,06E+04				18,01
8	4,5	24,25	31	139,5	3,06E+04				
9	4,5	28,75	31	139,5	3,06E+04				
10	4,5	33,25	31	139,5	3,06E+04				
11	4,9	37,95	31	151,9	3,06E+04				
12	1,6	41,2	31	45,58	3,06E+04	41,2	4,02	2,E+05	
13	3	43,5	31	93	3,06E+04				

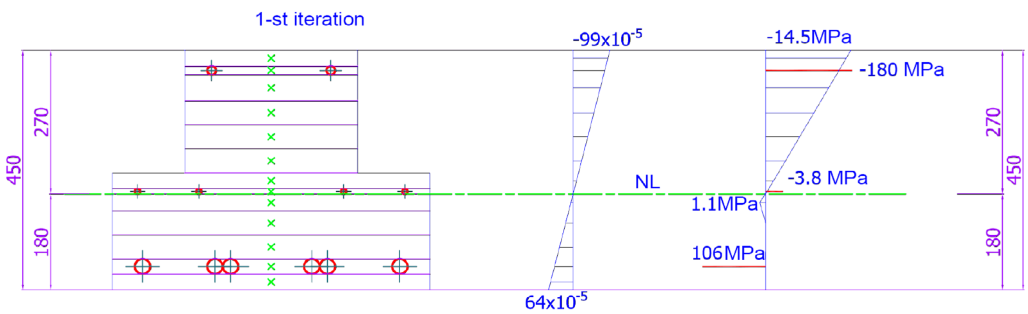


Figure 7. First iteration of the first method

DOI: 10.23968/2500-0055-2018-3-3-29-41

Table 2. First iteration of the first method

i	A_b, cm^2	E_b, MPa	A_s, cm^2	E_s, MPa	y_o_j, cm	y_b, cm	y_s, cm	$1/$, cm^{-1}	ε_b	σ_b, MPa	ε_s	σ_s, MPa
1	171	3.06E+04				16.51			6.41E-04	0.00		
2	122.8	3.06E+04	36.8	2.E+05		13.61	13.61		5.29E-04	0.00	5.29E-04	105.7
3	256.5	3.06E+04				9.96			3.87E-04	0.00		
4	256.5	3.06E+04				5.46			2.12E-04	0.00		
5	182.4	3.06E+04				1.61			6.26E-05	1.10		
6	53.86	3.06E+04	3.14	2.E+05		-0.49	-0.49		-1.89E-05	-0.28	-1.89E-05	-3.7846
7	171	3.06E+04			18.01	-2.49		3.88E-05	-9.66E-05	-1.42		
8	139.5	3.06E+04				-6.24			-2.42E-04	-3.55		
9	139.5	3.06E+04				-10.74			-4.17E-04	-6.11		
10	139.5	3.06E+04				-15.24			-5.92E-04	-8.68		
11	151.9	3.06E+04				-19.94			-7.74E-04	-11.35		
12	45.58	3.06E+04	4.02	2.E+05		-23.19	-23.19		-9.00E-04	-13.20	-9.00E-04	-180.05
13	93	3.06E+04				-25.49			-9.90E-04	-14.51		

Table 3. Second iteration of the first method

i	A_b, cm^2	E_b, MPa	A_s, cm^2	E_s, MPa	y_o_j, cm	y_b, cm	y_s, cm	$1/$, cm^{-1}	ε_b	σ_b, MPa	ε_s	σ_s, MPa
1	171	0.00E+00				19.66			1.88E-03	0.00		
2	122.8	0.00E+00	36.8	2.E+05		16.76	16.76		1.61E-03	0.00	1.61E-03	321.2
3	256.5	0.00E+00				13.11			1.26E-03	0.00		
4	256.5	0.00E+00				8.61			8.25E-04	0.00		
5	182.4	1.75E+04				4.76			4.56E-04	0.00		
6	53.86	1.47E+04	3.14	2.E+05		2.66	2.66		2.55E-04	0.00	2.55E-04	50.977
7	171	1.47E+04			21.16	0.66		9.58E-05	6.32E-05	1.11		
8	139.5	1.47E+04				-3.09			-2.96E-04	-4.34		
9	139.5	1.47E+04				-7.59			-7.27E-04	-10.67		
10	139.5	1.47E+04				-12.09			-1.16E-03	-16.99		
11	151.9	1.47E+04				-16.79			-1.61E-03	-22.00		
12	45.58	1.47E+04	4.02	2.E+05		-20.04	-20.04		-1.92E-03	-22.00	-1.92E-03	-355
13	93	1.47E+04				-22.34			-2.14E-03	-22.00		

of the lower stretched zone to the center of gravity, area and modulus of elasticity of i-n reinforcement, accordingly; $y_{0j} = y_{01} = 180\ \text{mm}$ – position of neutral line in the course of the first iteration.

Tables 2-9 and Figure 5-12 show the results of iteration calculations according to the first and the second methods.

Thus, the summary limiting moment according to Table 5:

$$M_{calc} = \sum \sigma_{bi} A_{bi} y_{bi}^{'} + \sum \sigma_{si} A_{si} y_{si}^{'} = 424.459 \cdot 10^6\ \text{N mm}$$

Height of compressed zone:

$$x = h - y_{011} = 45 - 21.09 = 24.91\ \text{cm}$$

Example of calculation according to the second iteration method

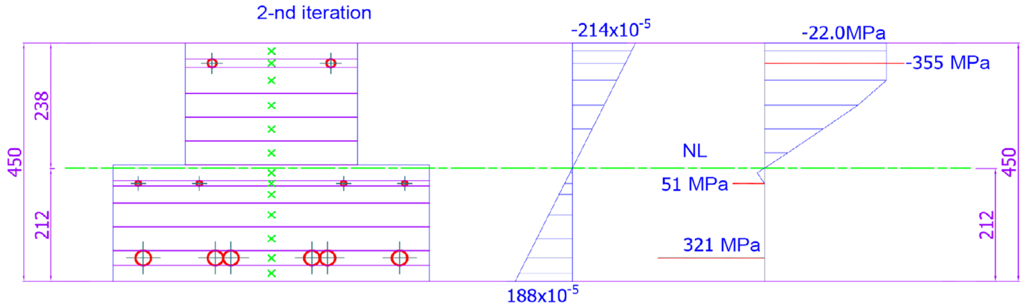


Figure 8. Second iteration of the first method

Table 4. Third iteration of the first method

i	A_b	E_b	A_s	E_s	y_o	y_b	y_s	$1/$	ε_b	σ_b	ε_s	σ_s
	cm^2	MPa	cm^2	MPa	cm	cm	cm	cm^{-1}		MPa		MPa
1	171	0.00E+00			21.21	19.71		1.05E-04	2.08E-03	0.00		
2	122.8	0.00E+00	36.8	2.E+05		16.81	16.81		1.77E-03	0.00	1.77E-03	354.41
3	256.5	0.00E+00				13.16			1.39E-03	0.00		
4	256.5	0.00E+00				8.66			9.13E-04	0.00		
5	182.4	0.00E+00				4.81			5.07E-04	0.00		
6	53.86	0.00E+00	3.14	2.E+05		2.71	2.71		2.86E-04	0.00	2.86E-04	57.219
7	171	1.75E+04				0.71			7.53E-05	1.32		
8	139.5	1.47E+04				-3.04			-3.20E-04	-4.69		
9	139.5	1.47E+04				-7.54			-7.94E-04	-11.65		
10	139.5	1.47E+04				-12.04			-1.27E-03	-18.60		
11	151.9	1.37E+04				-16.74			-1.76E-03	-22.00		
12	45.58	1.15E+04	4.02	2.E+05		-19.99	-19.99		-2.11E-03	-22.00	-2.11E-03	-355
13	93	1.03E+04				-22.29			-2.35E-03	-22.00		

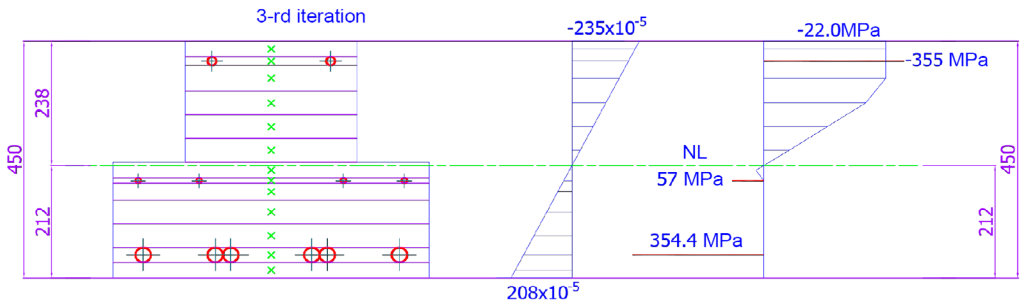


Figure 9. Third iteration of the first method

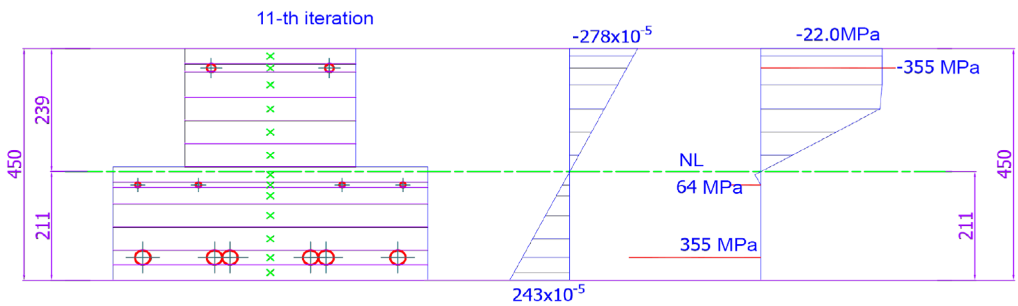


Figure 10. Eleventh iteration of the first method

DOI: 10.23968/2500-0055-2018-3-3-29-41

Table 5. Eleventh iteration of the first method

i	A_b	E_b	A_s	E_s	y_o	y_b	y_s	$1/\rho$	ε_b	σ_b	ε_s	σ_s
	cm^2	MPa	cm^2	MPa	cm	cm	cm	cm^{-1}		MPa		MPa
1	171	0.00E+00				19.59			2.43E-03	0.00		
2	122.8	0.00E+00	36.8	2.E+05		16.69	16.69		2.07E-03	0.00	2.07E-03	355
3	256.5	0.00E+00				13.04			1.61E-03	0.00		
4	256.5	0.00E+00				8.54			1.06E-03	0.00		
5	182.4	0.00E+00				4.69			5.81E-04	0.00		
6	53.86	0.00E+00	3.14	2.E+05		2.59	2.59		3.21E-04	0.00	3.21E-04	64.175
7	171	1.75E+04			21.09	0.59		1.24E-04	7.32E-05	1.28		
8	139.5	1.47E+04				-3.16			-3.91E-04	-5.74		
9	139.5	1.47E+04				-7.66			-9.48E-04	-13.91		
10	139.5	1.47E+04				-12.16			-1.51E-03	-22.00		
11	151.9	1.06E+04				-16.86			-2.09E-03	-22.00		
12	45.58	8.92E+03	4.02	1.E+05		-20.11	-20.11		-2.49E-03	-22.00	-2.49E-03	-355
13	93	8.01E+03				-22.41			-2.78E-03	-22.00		

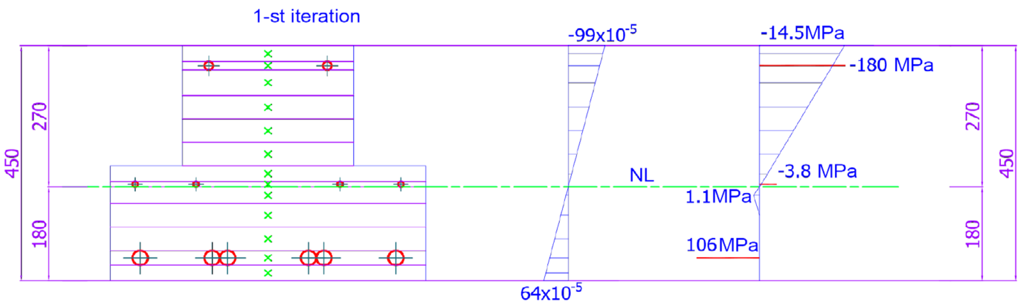


Figure 11. First iteration of the second method

Table 6. First iteration of the second method

i	Δ	y_b	b_b	A_b	E_b	y_s	A_s	E_s	ε_b	σ_b	ε_s	σ_s
	cm	cm	cm	cm^2	MPa	cm	cm^2	MPa		MPa		MPa
1	3	1.5	57	171	3.06E+04				6.41E-04	0.00		
2	2.8	4.4	57	122.8	3.06E+04	4.4	36.8	2.E+05	5.29E-04	0.00	5.29E-04	105.70
3	4.5	8.05	57	256.5	3.06E+04				3.87E-04	0.00		
4	4.5	12.6	57	256.5	3.06E+04				2.12E-04	0.00		
5	3.2	16.4	57	182.4	3.06E+04				6.26E-05	1.10		
6	1	18.5	57	53.86	3.06E+04	18.5	3.14	2.E+05	-1.89E-05	-0.28	-1.89E-05	-3.78
7	3	20.5	57	171	3.06E+04				-9.66E-05	-1.42		
8	4.5	24.3	31	139.5	3.06E+04				-2.42E-04	-3.55		
9	4.5	28.8	31	139.5	3.06E+04				-4.17E-04	-6.11		
10	4.5	33.3	31	139.5	3.06E+04				-5.92E-04	-8.68		
11	4.9	38	31	151.9	3.06E+04				-7.74E-04	-11.35		
12	1.6	41.2	31	45.58	3.06E+04	41.2	4.02	2.E+05	-9.00E-04	-13.20	-9.00E-04	-180.05
13	3	43.5	31	93	3.06E+04				-9.90E-04	-14.51		

Table 7. Second iteration of the second method

i	y_b	b_b	A_b	E_b	y_s	A_s	E_s	ε_b	σ_b	ε_s	σ_s
	cm	cm	cm^2	MPa	cm	cm^2	MPa		MPa		MPa
1	1.5	57	171	0.00E+00				1.88E-03	0.00		
2	4.4	57	122.8	0.00E+00	4.4	36.8	2.E+05	1.61E-03	0.00	1.61E-03	321.20
3	8.05	57	256.5	0.00E+00				1.26E-03	0.00		
4	12.6	57	256.5	0.00E+00				8.25E-04	0.00		
5	16.4	57	182.4	1.75E+04				4.56E-04	0.00		
6	18.5	57	53.86	1.47E+04	18.5	3.14	2.E+05	2.55E-04	0.00	2.55E-04	50.98
7	20.5	57	171	1.47E+04				6.32E-05	1.11		
8	24.3	31	139.5	1.47E+04				-2.96E-04	-4.34		
9	28.8	31	139.5	1.47E+04				-7.27E-04	-10.67		
10	33.3	31	139.5	1.47E+04				-1.16E-03	-16.99		
11	38	31	151.9	1.47E+04				-1.61E-03	-22.00		
12	41.2	31	45.58	1.47E+04	41.2	4.02	2.E+05	-1.92E-03	-22.00	-1.92E-03	-355.00
13	43.5	31	93	1.47E+04				-2.14E-03	-22.00		

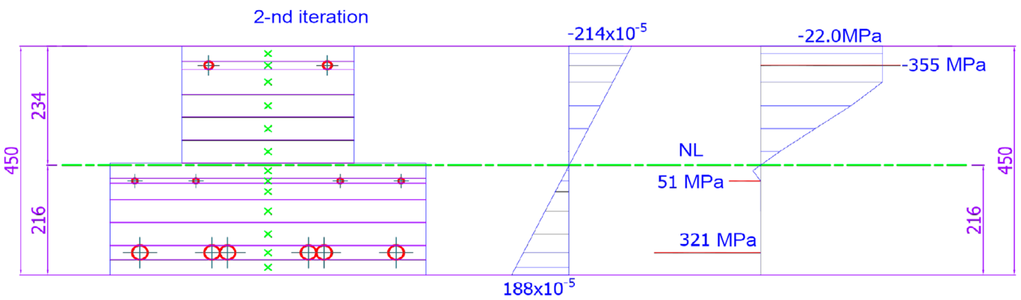


Figure 12. Second iteration of the second method

Table 8. Third iteration of the second method

i	y_b	b_b	A_b	E_b	y_s	A_s	E_s	ε_b	σ_b	ε_s	σ_s
	cm	cm	cm^2	MPa	cm	cm^2	MPa		MPa		MPa
1	1.5	57	171	0.00E+00				2.08E-03	0.00		
2	4.4	57	122.8	0.00E+00	4.4	36.8	2.E+05	1.77E-03	0.00	1.77E-03	354.41
3	8.05	57	256.5	0.00E+00				1.39E-03	0.00		
4	12.6	57	256.5	0.00E+00				9.13E-04	0.00		
5	16.4	57	182.4	0.00E+00				5.07E-04	0.00		
6	18.5	57	53.86	0.00E+00	18.5	3.14	2.E+05	2.86E-04	0.00	2.86E-04	57.22
7	20.5	57	171	1.75E+04				7.53E-05	1.32		
8	24.3	31	139.5	1.47E+04				-3.20E-04	-4.69		
9	28.8	31	139.5	1.47E+04				-7.94E-04	-11.65		
10	33.3	31	139.5	1.47E+04				-1.27E-03	-18.60		
11	38	31	151.9	1.37E+04				-1.76E-03	-22.00		
12	41.2	31	45.58	1.15E+04	41.2	4.02	2.E+05	-2.11E-03	-22.00	-2.11E-03	-355.00
13	43.5	31	93	1.03E+04				-2.35E-03	-22.00		

DOI: 10.23968/2500-0055-2018-3-3-29-41

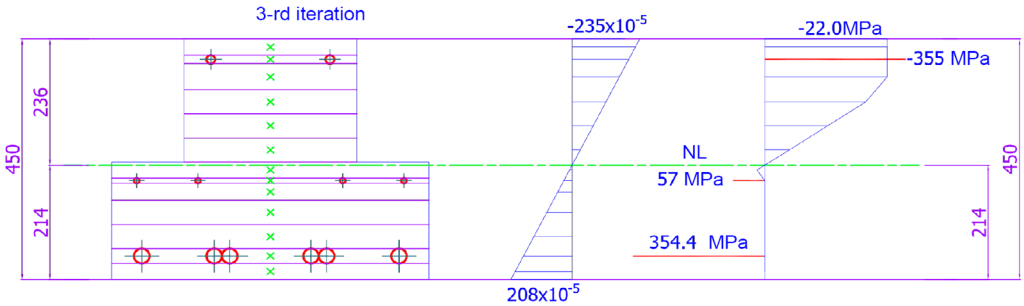


Figure 13. Third iteration of the second method

Table 9. Eleventh iteration of the second method

i	y_b	b_b	A_b	E_b	y_s	A_s	E_s	ε_b	σ_b	ε_s	σ_s
	cm	cm	cm^2	MPa	cm	cm^2	MPa		MPa		MPa
1	1.5	57	171	0.00E+00				2.40E-03	0.00		
2	4.4	57	122.8	0.00E+00	4.4	36.8	2.E+05	2.04E-03	0.00	2.04E-03	355.00
3	8.05	57	256.5	0.00E+00				1.59E-03	0.00		
4	12.6	57	256.5	0.00E+00				1.04E-03	0.00		
5	16.4	57	182.4	0.00E+00				5.70E-04	0.00		
6	18.5	57	53.86	0.00E+00	18.5	3.14	2.E+05	3.12E-04	0.00	3.12E-04	62.40
7	20.5	57	171	1.75E+04				6.66E-05	1.17		
8	24.3	31	139.5	1.47E+04				-3.94E-04	-5.77		
9	28.8	31	139.5	1.47E+04				-9.46E-04	-13.87		
10	33.3	31	139.5	1.47E+04				-1.50E-03	-21.97		
11	38	31	151.9	1.07E+04				-2.07E-03	-22.00		
12	41.2	31	45.58	8.99E+03	41.2	4.02	1.E+05	-2.47E-03	-22.00	-2.47E-03	-355.00
13	43.5	31	93	8.07E+03				-2.76E-03	-22.00		

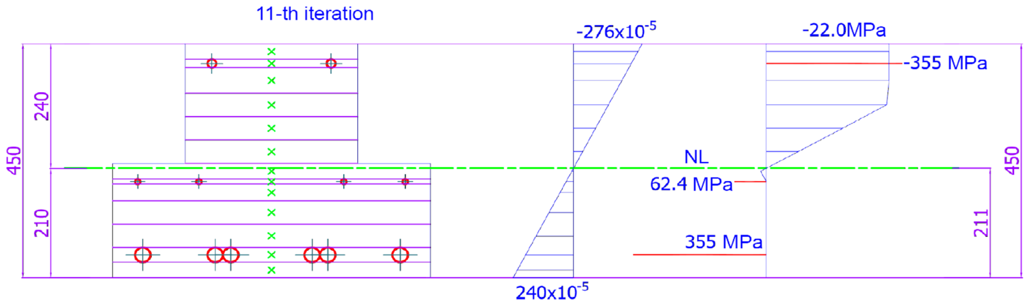


Figure 14. Eleventh iteration of the second method

The relative deformations get determined depending on stiffness characteristics of every small area. The determination of height of compressed zone and graphical presentation of strain-stress state of cross section in the course of every iteration have been built depending on the calculated values of stresses and deformations with adherence to scale.

Table 10. Comparison of calculation parameters.

Calculation method	Deformations	Load-carrying ability, kNm	Height of compressed zone, cm
With respect to limiting conditions	–	430.0	18.7
Deformation calculation 1	$\varepsilon_{bc,calc} = 2.78 \cdot 10^{-3} < \left[\varepsilon_{b2} = 3.5 \cdot 10^{-3} \right]$ $\varepsilon_{s,calc} = 0.00207 < \left[\varepsilon_{s2} = 0.025 \right]$	424.5	24.91
Deformation calculation 2	$\varepsilon_{bc,calc} = 2.76 \cdot 10^{-3} < \left[\varepsilon_{b2} = 3.5 \cdot 10^{-3} \right]$ $\varepsilon_{s,calc} = 0.00204 < \left[\varepsilon_{s2} = 0.025 \right]$	427.8	24.06

The height of compressed zone following a principle of "similarity of triangles" will be determined according to:

$$x_j = \frac{h}{\frac{\varepsilon_1}{|\varepsilon_{13}|} + 1}$$

Thus, the summary limiting moment according to Table 9:

$$M_{calc} = \sum \sigma_{bi} A_{bi} y'_{bi} + \sum \sigma_{si} A_{si} y'_{si} = 427.795 \cdot 10^6 \text{ N mm}$$

We determine a height of the compressed zone through deformations using "indicators of similarity of triangles":

$$x = \frac{h}{1.86956} = \frac{45}{1.86956} = 24.06 \text{ cm}$$

Conclusion

The results presented in Table 10 testify to the fact that the acquired design values of deformations feature insignificant differences in case of calculations according to methods 1 and 2 and become adequately consistent with calculation data with respect to limiting conditions, which also proves adequacy of the developed methods.

References

Boujelben, A., Ibrahimbegovic, A. (2017). Finite-strain three-dimensional solids with rotational degrees of freedom: non-linear statics and dynamics). *Advanced Modeling and Simulation in Engineering Sciences*, 4 (1), 3. DOI: 10.1186/s40323-017-0089-9

Dalla Valle, P., Thom, N. (2018). Improvement to method of equivalent thicknesses (MET) for calculation of critical strains for flexible pavements. *International Journal of Pavement Engineering*, 19 (12), pp. 1053–1060. DOI: 10.1080/10298436.2016.1238698

Fatehiboroujeni, S., Palanthandalam-Madapusi, H.J., Goyal, S. (2018). Computational Rod Model with User-Defined Nonlinear Constitutive Laws. *Journal of Computational and Nonlinear Dynamics*, 13(10), 101006. DOI: 10.1115/1.4041028

Jagtap, K.R., Lal, A., Singh, B.N. (2018). Uncertainty quantification in non-linear dynamic response of functionally graded materials plate. *Mechanics of Advanced Materials and Structures*, 25 (13), pp. 1081–1100. DOI: 10.1080/15376494.2017.1329465

Kong, G., Zhou, Y., Liu, H. (2018). Nonlinear model analysis of radial bulging deformation of geosynthetic-encased stone columns. *International Journal of Geomechanics*, 18 (10), 06018022. DOI: 10.1061/(ASCE)GM.1943-5622.0001195

Mao, J.-J., Zhang, W. (2018). Linear and nonlinear free and forced vibrations of graphene reinforced piezoelectric composite plate under external voltage excitation. *Composite Structures*, 203, pp. 551–565. DOI: 10.1016/j.compstruct.2018.06.076

Minstroy RF (2013). *SP 63.13330.2012. Concrete and reinforced-concrete structures. Basic provisions*. Updated issue of SNiP 52-01–2003 (with revision Nos 1, 2), Moscow. (in Russian)

Morozov, V.I., Opbul, E.K. (2016). Raschet izgibaemyh stalefibrozhelezobetonnyh ehlementov po nelinejnoj deformacionnoj modeli s sipol'zovaniem opytnyh diagramm deformirovaniya stalefibrobetona [Calculation of bending steel fiber reinforced-concrete members according to non-linear deformation with the use of experimental diagrams of deformation of steel fiber reinforced-concrete]. *Vestnik grazhdanskikh ingenerov [Bulletin of Civil Engineers]*, 5 (58), pp. 51–55. (in Russian)

Opbul, E.K., Dmitriev, D.A., Vedernikova, A.A. (2017). Nelinejno-iteracionnyj raschet prochnosti stalefibrozhelezobetonnyh ehlementov s sipol'zovaniem opytnyh diagramm deformirovaniya materialov [Non-linear and iteration calculation of strength of steel fiber reinforced-concrete members with the use of experimental diagrams of materials deformation]. *Vestnik grazhdanskikh ingenerov [Bulletin of Civil Engineers]*, 1 (60), pp. 79–91. (in Russian)

Patni, M., Minera, S., Groh, R.M.J., Pirrera, A., Weaver, P.M. (2018). Three-dimensional stress analysis for laminated composite and sandwich structures. *Composites Part B: Engineering*, 155, pp. 299–328. DOI: 10.1016/j.compositesb.2018.08.127

TsRIIPromzdaniy OJSC (2005). *Guidebook for designing concrete and reinforced-concrete structures from heavy concrete without pre-stressing (to SP 52-101-2003)*, Moscow. (in Russian)

COMPREHENSIVE ASSESSMENT OF THE EFFECTIVE USE OF PACKAGE UNITS TO SORT MUNICIPAL SOLID WASTE

Valentin Penchuk[1], Vitalii Datsenko[2], Yurii Novichkov[3]

[1,2,3] Donbas National Academy of Civil Engineering and Architecture
Derzhavina st., 2, Makeevka

[2] dacenko-vital@mail.ru

Abstract

Based on conclusions made in research into municipal waste processing, it is established that the existing technologies using stationary sorting plants most often involve special trucks that compact municipal solid waste (MSW) transported, which results in decreasing the plant efficiency. Preliminary MSW compacting during transportation significantly complicates the sorting process; at the compression ratio , time spent to sort the i-th volume of waste increases up to 30%.

A method proposed to run the feasibility analysis of the process involving the use of a package unit to sort MSW allows establishing the area of its application.

Keywords

Sorting, solid waste, block plant, construction.

Introduction

In the 21st century, the variety of consumer products is constantly growing, the number of packaging types for product delivery and storage is increasing, therefore, the amount of waste is increasing as well and the environmental situation is deteriorating every year. One of the many sources generating municipal solid waste (MSW) is cultural events. Improving the efficiency of processing MSW generated during mass events and reducing the cost of these operations have always been and will continue to be relevant.

Literature review

The environmental issue associated with municipal solid waste stays in focus of numerous studies. Several papers (Babanin, 2006; Bilitewski, Dornak, 2006; Bukhgalter et al., 2004; Veprentsev, 2006; Christensen et al., 1999) address various administrative and economic aspects of waste disposal and garbage disposition in inhabited areas. Segregated MSW collection directly at waste generation sites is discussed (Babanin, I2005). Involvement and active participation of local residents represent the most important element in successful implementation of large-scale projects for segregated MSW collection. Modern trends in areas of management, monitoring, and engineering solutions related to the issue of waste management and modern methods of waste processing are explored (Grinin, Novikov, 2002; Kasimov et al., 2007; Krasnyansky, 2007; Podchezertseva, 2005; Chekalin, 2001).

Issues dealing with advantages and prospects of the processing industry in the European Union are addressed (Bontoux et al., 1996; Dubois et al., 2004; Pires et al., 2011; Planning for solid waste & recycling. City of Boise

DOI: 10.23968/2500-0055-2018-3-3-42-50

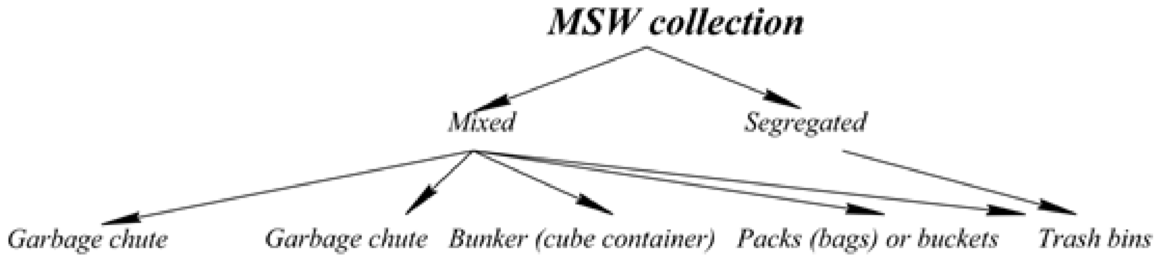


Figure 1. Methods of MSW collection

Planning & Development Services, 2008). Specifically, the Directive on the prevention of air pollution from new municipal waste incineration plants is considered (Council Directive on the prevention of air pollution from new municipal waste incineration plant, 1989). Methods of waste management in medical facilities and management/restoration of landfills set up under urban/suburban conditions are studied (Overmann et al., 1999).

Problem statement

The goal of this study is associated with justifying the efficiency of using package units to sort municipal solid waste.

The following tasks were formulated to achieve the goal:

- identifying types of mass events;
- assessing the impact of the MSW compaction degree on sorting quality and time;
- justifying areas of rational using of package and mobile sorting units, as well as their design features;

Study background

Mass events involve meetings, rallies, demonstrations, processions, religious (cult) and spiritual/educational meetings, picketing, sport events, cultural and entertainment events, presentation, advertising and other events held in accordance with the effective legislation.

During such events, a certain amount of MSW having specific fraction composition is generated.

Referring to the work of Krasnyansky (2004), we can estimate the amount of recyclables contained in MSW and its accumulation rate.

Table 1. The average content of recyclables in MSW

MSW amount (m^3/person per day)	MSW amount (m^3/person per year)	MSW mass (kg/person per day)	MSW density (kg/m^3)	MSW composition (% wt)
0.0029	0.99	0.59	217.1	Waste paper — 40 Glass — 25 Plastics — 15 Metal — 5 Other — 15

Given that the number of people attending public events can be in the range from 1 to 50 thousand or even more and the average duration of an event can be 3–4 hours, we can talk about the MSW amount of 0.5–25 m^3. As is shown in Table 1, the waste fraction composition is almost completely suitable for recycling, which, in turn, indicates a need for waste sorting.

At the present time, there are the following approaches to collect MSW (Figure 1):

- mixed (residents collect MSW generated in daily life in a single container);
- segregated (residents individually sort garbage into fractions).

It is difficult to arrange segregated waste collection in public places during mass events as it is not possible to set up a large number of trash bins and containers for each type of fraction.

Mixed collection implies transportation of waste using specialized public trucks. Modern trucks and equipment for loading and transporting municipal waste are equipped with mechanisms for forced compression with degree ξ = 4...5 to increase the mass of waste transported in a single cycle. Studies on the effect of compacting MSW on the sorting time carried out at the premises of the Donbas National Academy of Civil Engineering and Architecture (Department of Lifting and Transporting, Construction and Road Machinery and Equipment) (Penchuk, Datsenko, 2012, 2013) showed that, at the compression ratio of 4, time spent on sorting increased up to 30% (Figure 2).

In this regard, the most rational is sorting of waste near places of its formation using package units, a design scheme and prototype of which are shown in Figures 5 and 6.

MSW product sorting using a conveyor belt can be referred to as smooth continuous production which ensures the shortest duration of production cycles. Depending on the collection site, MSW products can be sorted into 4–7 fractions.

Equal operating cycles are necessary for continuous production; in such case, the duration of collecting individual fractions should be equal to:

$$t_{WP} = t_G = t_{PET} = t_{MET} = t_{TEX} = t_{EST}, \quad (1)$$

where $t_{WP}; t_G; t_{PET}; t_{MET}; t_{TEX}$ are respective intervals of time spent on waste paper, glass, plastic, metal and textiles collection;

t_{EST} is arbitrary time of conveyor movement or estimated conveyor movement rate.

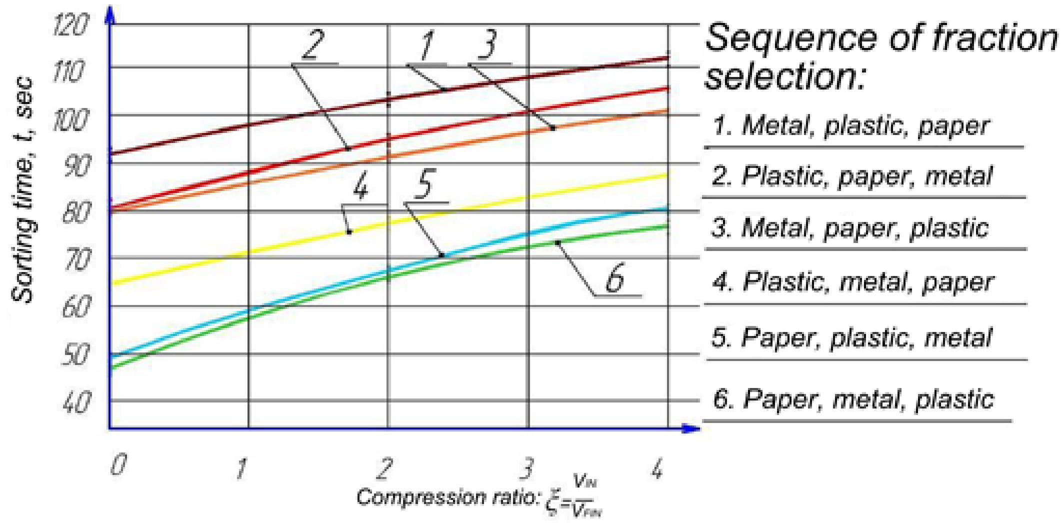


Figure 2. A dependence of the sorting time on the compression ratio and sequence of MSW fraction selection

Figure 3. A general view of MSW compaction bench:
1 — a drive; 2 — a bench frame; 3 — a box simulating the garbage truck body; 4 — a sensor to measure the compaction force; 5 — a compactor plate; 6 — a computer; 7 — an amplifier power supply; 8 — a National Instruments controller for signal transformation; 9 — a four-channel amplifier; 10 — a frequency control unit of the drive.

(a) (b) (c)

Figure 4. Phases of MSW compression:
a) ξ = 0; b) ξ = 2; c) ξ = 4

DOI: 10.23968/2500-0055-2018-3-3-42-50

(a) (b)

(c) (d)

Figure 5. A package unit for MSW sorting:
a — MSW sorting process; b — process of collecting sorted recyclables; c — sorted waste paper; d — sorted plastic and polyethylene

It is necessary to mention such parameter as estimated conveyor movement mode which entirely depends on physiological capabilities of the operator. Initially, the operator should visually find the required item on the conveyor belt, and, according to the data, time spent for this operation amounts to $t_{vis} = 0.5...1$ s.

Then the operator performs an operation of manual gripping t_{grip} moving the item to the receiving opening t_{mov} and lowering it into the receiving opening t_{low}. Therefore, a working cycle of an operator can be represented as follows:

$$t_{oper} = t_{vis} + t_{grip} + t_{mov} + t_{low} \quad (2)$$

If we represent the operating conveyor as areas to collect the corresponding MSW components, then the calculation scheme can be given as follows (Figure 7).

The conveyor movement rate can be calculated based on capabilities of the operator. If we denote the length of the working area, which can be handled by a human hand without stress, as L_W, then the dependence for the estimated time can be written as follows:

$$t_{EST} = \frac{L_W}{v_b} \quad (3)$$

Then the number of working cycles of an operator will amount to:

$$n_c = \frac{t_{EST}}{t_{oper}} = \frac{L_W}{v_b} \cdot \frac{1}{t_{vis} + t_{grip} + t_{mov} + t_{low}} \quad (4)$$

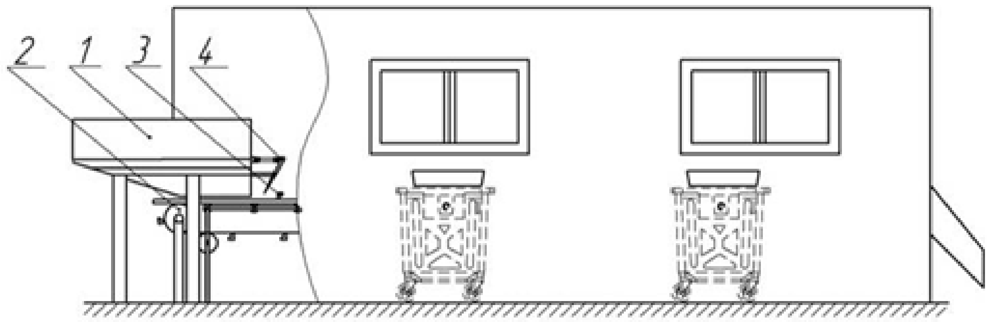


Figure 6. A structural scheme of a package unit:
1 — receiving hopper; 2 — a belt conveyor; 3 — conveyor grips; 4 — spring-loaded blades for tearing and loosening of polyethylene bags

If we assume that in the amount of MSW located along the estimated length of the conveyor belt section L_W there is an n_i number of fractions, then the required number of stations to collect those fractions can be represented as follows:

$$k_{WP} = \frac{n_{WP}}{n_c};\quad k_G = \frac{n_G}{n_c};\quad k_{PET} = \frac{n_{PET}}{n_c}$$

$$k_{MET} = \frac{n_{MET}}{n_c};\quad k_{TEX} = \frac{n_{TEX}}{n_c} \qquad (5)$$

If the required number of stations is more than 1, then the value obtained is rounded upwards.

The operation of individual stations can be synchronized using numerous technical and organizational arrangements.

Preliminary synchronization can be achieved by combining options of fraction collection:

1) waste paper, glass, PET, metal, textiles;
2) glass, waste paper, PET, metal, textiles;
3) PET, waste paper, glass, metal, textiles;
4) metal, waste paper, glass, PET, textiles;

etc.

In order to select a more rational technology for selecting MSW components, a preliminary experiment on selecting fractions or fine-tuning the sorting line in a production environment should be carried out in the following manner:

- individual staffing to carry out specific operations;
- adjustment of the conveyor belt speed;
- introduction of auxiliary personnel;
- preliminary sorting of large-size fractions.

In accordance with the calculation scheme (Figure 7) and equation (5), the required length of the conveyor belt can be determined using the following equation:

$$L_{conv} = L_W \cdot (k_{WP} + k_G + k_{PET} + k_{MET} + k_{TEX}) \qquad (6)$$

If a certain operation deviates significantly from standard, it is recommended to set up buffer areas or introduce the function of adjusting the conveyor belt speed.

To assess quality indicators of any sorting technology, we can apply the sorting level parameter:

$$E_{sort} = \frac{\sum_{i=1}^{n} m_i}{m_{TAIL}} \qquad (7)$$

where $\sum_{i=1}^{n} m_i$ is the total MSW mass;

m_{TAIL} is the mass of material "tailings" remaining after sorting.

A better picture can be obtained through analyzing the structure of MSW tailings. In this case, it will be possible to establish the efficiency of sorting for each fraction:

$$E_{sort}^{WP} = \frac{m_{TAIL}^{WP}}{m_{WP} + m_{TAIL}}$$

$$E_{sort}^{G} = \frac{m_{TAIL}^{G}}{m_G + m_{TAIL}} \qquad (8)$$

....

$$E_{sort}^{i} = \frac{m_{TAIL}^{i}}{m_i + m_{TAIL}}$$

This allows identifying the most important operations and introducing adjustments into the sorting technology.

Parameters of the sorting process mainly depend on the state of *od1* operand, or the cost.

The initial state of MSW (*od1* operand) means its morphological composition and compression ratio during delivery.

The initial cost of MSW products implies the cost associated with waste collection, storage, loading and delivery. It can still be assumed that MSW itself is free.

Generally, the efficiency function of a particular technology for MSW processing can be written as follows:

$$E^{MSW} = \sum_{i=1}^{n}\sum_{j=1}^{m} O_{ij} \cdot \gamma_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij} \to \max \qquad (9)$$

where O_{ij} — output from processing of the *i-th* kind of municipal waste using technology *j*;

γ_{ij} — contract price of the *i-th* type of municipal waste using technology *j*;

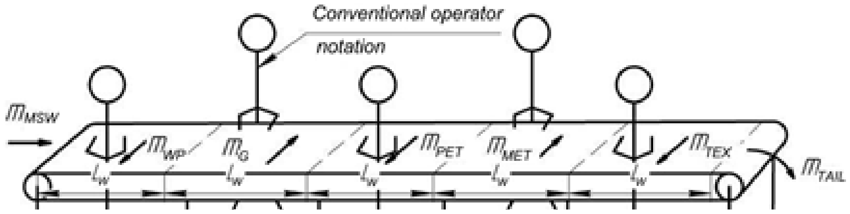


Figure 7. A calculation scheme to collect MSW fractions:
m_{WP} — waste paper; m_G — glass; m_{PET} — plastic; m_{PET} — metal; m_{TEX} — textiles; m_{TAIL} — tailings; L_W — length of the operator's working area.

DOI: 10.23968/2500-0055-2018-3-3-42-50

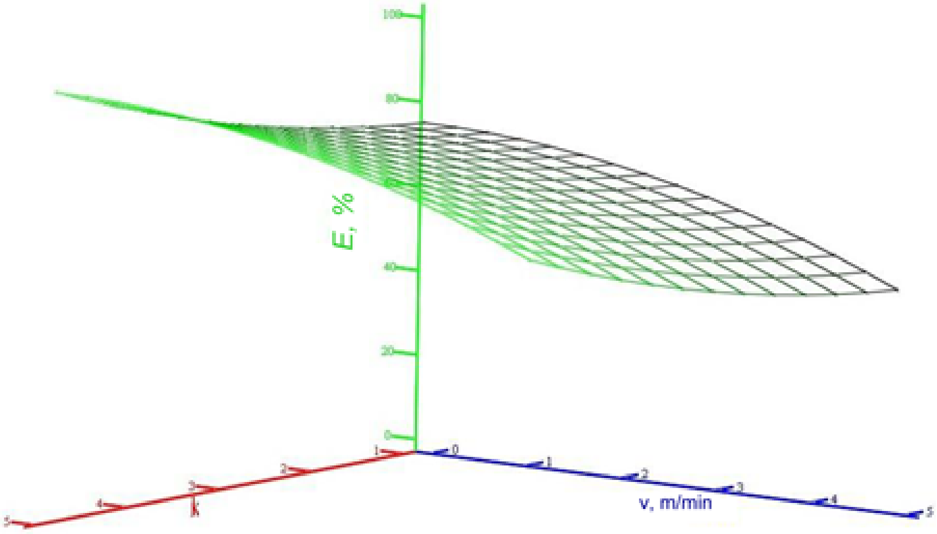


Figure 8. A dependence of the sorting efficiency on the conveyor speed and the number of stations to collect the *i-th* fraction

C_{ij} — costs for physical and power resources, associated with processing the i-th type of waste using technology *j*;

In order to identify the most rational technology for processing municipal waste, *j* directions of MSW movement shall be analyzed.

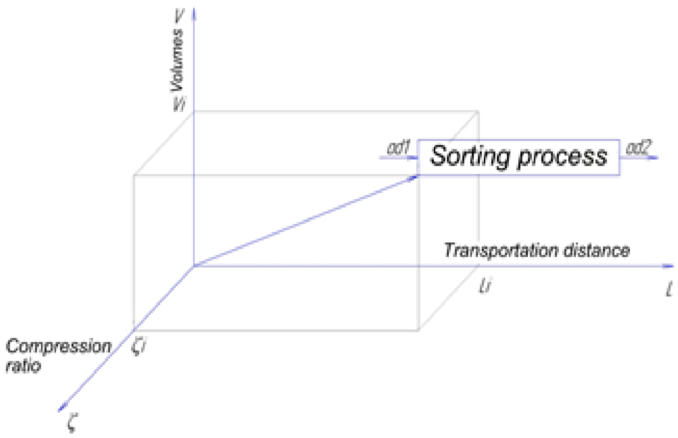


Figure 9. An MSW sorting process:
od1 — an operand of the initial state of MSW products (volume, compression ratio, transportation distance); *od2* — an operand of the state of MSW products after sorting (volume, compression ratio, transportation distance)

If we assume that, after sorting into fractions, fraction quantity and quality is the same in all technologies, that the following can be accepted:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} O_{ij}\cdot\gamma_{ij} \approx \sum_{i=1}^{n}\sum_{j=1}^{m} O_{i(j+1)}\cdot\gamma_{i(j+1)} \rightarrow \max \qquad (10)$$

Each individual object (school, university, hospital, recreation center, district, city, etc.) has its own specific MSW characteristics in terms of volume, nature of collection, distance, etc., but in all cases works shall be carried out in an efficient manner and with minimum costs.

In general, the function of cost optimization associated with MSW processing can be expressed as follows:

$$C_{sp}^{MSW} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij}}{\sum_{i=1}^{k} O_{ij}\cdot\gamma_{ij}} \rightarrow \min \qquad (11)$$

where C_{ij} — costs for physical and power resources associated with collecting and transporting $\sum_{i=1}^{k} O_{ij}$ of MSW.

In this case, the efficiency of technology j depends only on particular costs for physical and power resources.

In this case, the efficiency of technology j depends only on particular costs for physical and power resources.

$$\sum C_{od\,2} = C_{acc}^{j} + C_{load}^{j} + C_{del}^{j} + C_{sort}^{j} \qquad (12)$$

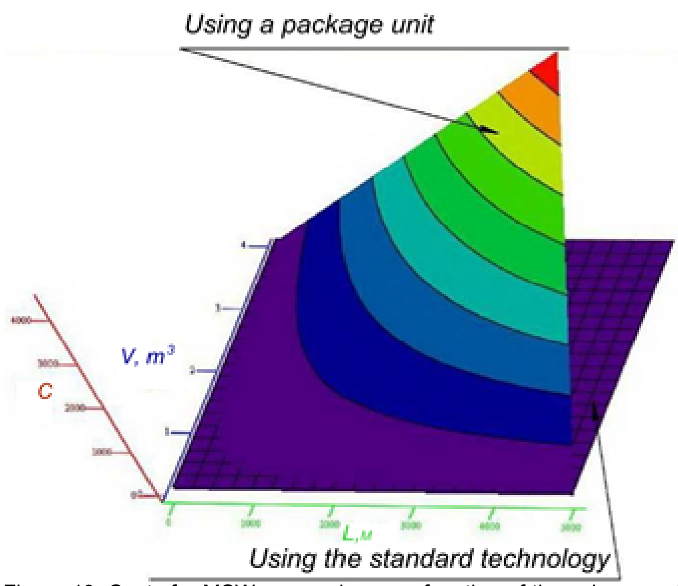


Figure 10. Costs for MSW processing as a function of the volume and transportation distance

where $C_{acc}^{j};C_{load}^{j};C_{del}^{j};C_{sort}^{j}$ are costs for physical and power resources, associated with accumulation, loading, delivery and sorting of MSW using technology *j*.

In case the output of MSW processing increases, the specific costs change accordingly. It is necessary to establish the level of specific costs for the *j-th* direction to determine the rational technology for MSW processing under specific conditions taking into account the waste volume and transportation distance.

$$\frac{\sum C_{od2}}{\sum_{i=1}^{n} O_n^j} = \frac{C_{acc}^j}{\sum_{i=1}^{n} O_i^j} = \frac{C_{load}^j}{\sum_{i=1}^{n} O_i^j} = \frac{C_{del}^j}{\sum_{i=1}^{n} O_i^j} = \frac{C_{sort}^j}{\sum_{i=1}^{n} O_i^j} \quad (13)$$

When the volume of MSW processing and the distance of transportation change, the specific costs change accordingly. It is necessary to consider the MSW movement in all possible directions and take the partial derivatives of the following functions in order to find the rational technology for municipal waste processing:

$$\frac{d(\sum C_{od2}^1)}{d(\sum_{i=1}^{n} O_n^1)} = 0$$

$$\frac{d(\sum C_{od2}^2)}{d(\sum_{i=1}^{n} O_n^2)} = 0 \quad (14)$$

$$\ldots$$

$$\frac{d(\sum C_{od2}^j)}{d(\sum_{i=1}^{n} O_n^j)} = 0$$

The roots of system of equations (14) can be represented as the following system of equations:

$$C_{ji1} = f(P_{i1}^1;P_{i1}^2;P_{i1}^3 \ldots P_{i1}^n) \cdot \sum_{i=1}^{n} O_{i=1}^1$$

$$C_{ji2} = f(P_{i2}^1;P_{i2}^2;P_{i2}^3 \ldots P_{i2}^n) \cdot \sum_{i=1}^{n} O_{i=2}^2 \quad (15)$$

$$\ldots$$

$$C_{jin} = f(P_{in}^1;P_{in}^2;P_{in}^3 \ldots P_{in}^n) \cdot \sum_{i=1}^{n} O_{i=n}^n$$

where $P_{i1}^1;P_{i1}^2;P_{i1}^3 \ldots P_{in}^n$ are factors representing functions of current parameters and modes of the MSW processing line;

$\sum_{i=1}^{n} O_n^j$ — the total material flow of MSW determines the output of each element in the processing line, i.e. costs associated with its manufacturing and maintenance. The process examines the possibility of distributing the main flow $\sum O_{ij}$ into several independent flows, i.e. setting up several lines working in parallel.

$$\sum_{i=1}^{n} O_{ij} = O_{j1}^1;O_{j2}^2;O_{j3}^3 \ldots O_{jn}^n \quad (16)$$

The method of finding the extremum of functions allows achieving complete adequacy in managing decisions in each specific situation.

It is quite obvious that the MSW processing technology option is superior if it has a mobility in the main element (sorting equipment) allowing adapting the process to specific conditions.

Comparison of the cost of MSW processing using a package unit and using the standard technology depending on the MSW volume and transportation distance is given in Figure 10.

Based on the data, the following can be concluded:

- the use of a package unit for MSW sorting is feasible at volumes up to 2 m^3 in case the distance between stations is up to 1 km;

- the use of the standard technology involving stationary plants is feasible only in case of large scope of work.

Conclusion

1. A package unit for MSW sorting is a temporary stationary sorting unit where collection, delivery and sorting are carried out manually. When choosing the standard size of package units, the most important parameters are MSW volume and hand-delivery distance. According to the numerical analysis, the use of package units is most effective for MSW volumes $V \le 2$ m^3 and distance of collection and delivery $L \le 1$ km.

2. The main part of any unit for MSW sorting consists of a standard belt conveyor having a width of 0.8...1.0 m to suit anthropometric characteristics of operators; the length of the belt should be consistent with the number of operators collecting particular fractions. The speed of the conveyor belt controls MSW sorting quality; it depends on the speed of human eye and muscle movement. The boundaries of the conveyor belt speed are theoretically established and stay within $V = 0.5 \ldots 5$ m/min limit. Depending on the volumes, the fraction composition and required quality of MSW sorting, it is recommended to adjust the conveyor speed using a variable-frequency electric drive.

DOI: 10.23968/2500-0055-2018-3-3-42-50

3. Preliminary MSW compacting used to increase the MSW mass upon one-off delivery to a sorting unit significantly complicates the sorting process. At the MSW compression ratio $\xi = 4$, time spent on sorting increases up to 30%. When sorting MSW products, the best sequence of MSW fraction collection depends on the MSW morphological composition. The most rational sequence for MSW fraction collection for educational and sport facilities (stadiums, race tracks), recreation centers, etc. is as follows: waste paper; plastic; glass; metal.

References

Babanin, I.V. (2005). *Justification of necessity and requirements to schemes for segregated collection of municipal waste*. Available at: http://waste.com.ua (accessed on: 14.06.2018)

Babanin, I.V. (2006). Evaluating the efficiency of segregated waste collection. *Municipal Solid Waste*, 7, pp. 40–43.

Bilitewski, B., Dornak, K. (2006). Waste management in Germany. *Municipal Solid waste*, 10, pp. 54–57.

Bontoux, L., Leone F., Nicolai M. (1996). *The recycling industry in the European Union: impediments and prospects.* A report prepared by IPTS for the Committee for Environment, Public Health and Consumer Protection of the European Parliament.

Bukhgalter, E.B., Budnikov, B.O., Budnikova, O.A. (2004). Waste management as the most important direction of sustainable development in European Union countries. *Industrial Ecology*, 10, pp. 45–57.

Chekalin, V.S. (2001). *Strategic management in urban economy: study guide.* Saint Petersburg: Saint Petersburg State University of Engineering and Economics.

Christensen, T., Cossu, R., Stegmann, R. (1999). Waste management and treatment of municipal and industrial waste. In: *Proceedings of 7th International Waste Management and Landfill Symposium*, Sardinia.

Council Directive on the prevention of air pollution from new municipal waste incineration plant (1989). Official Journal of the European Communities, 163, pp. 32–36.

Dubois, M., González, A., Knadel, M. (2004). *Municipal solid waste treatment in the EU*. Environmental Studies, Aarhus University.

Fedorov, L.G. (1999). *Waste management in large cities and agglomeration settlement systems.* Moscow: Prima-Press-M.

Grinin, A.S., Novikov, V.N. (2002). *Industrial and municipal waste: storage, disposal, recycling: study guide.* Moscow: FAIR-PRESS.

Kasimov, A.M., Semenov, V.T., Aleksandrov, A.N., Kovalenko, A.M. (2007). *Municipal solid waste. Technologies and equipment. Problems and solutions.* Kharkiv: Kharkiv National Academy of Municipal Economy.

Krasnyansky, M.E. (2007). *Waste disposal and recycling: study guide. 2nd edition.* Kharkiv: Burun i K., Kiev: KNT.

Krasnyansky, M.E., Belgasem, A., Kalinikhin, O.N. (2004). *Analyzing flows of recyclables in municipal solid waste of Donetsk. In: Problems of collection, processing and disposal of waste.* Odessa: Odessa Center of Scientific, Technical and Economic Information.

Lyubarskaya, M.A. (2004). *MSW management: study guide.* Saint Petersburg: Saint Petersburg State University of Engineering and Economics.

Overmann, L.K., Lo, Y.C., Broadgate, J.S. (1999). *Waste treatment facility management — restoration of landfills in urban/sub-urban environments.* Environmental impact, aftercare and remediation of landfills, Sardinia, SIWMLS.

Penchuk, V.A., Datsenko, V.M. (2013). Specifics and trends in developing technologies for municipal waste processing. *Innovations in Science — Innovations in Education: Proceedings of the International Scientific and Technical Conference "Interstroymekh 2013".* Novocherkassk: Platov South-Russian State Polytechnic University (NPI).

Penchuk, V.O., Datsenko, V.M. (2012). Use of package and mobile units for efficient MSW management. In: *Proceedings of the National Ecological Forum "Ecology in Industrial Regions"*, Volume 1.

Pires, A., Martinho, G., Chang, N.-B. (2011). Solid waste management in European countries: a review of systems analysis techniques. *Journal of Environmental Management*, 92 (4), pp. 1033–1050.

Planning for solid waste & recycling (2008). City of Boise Planning & Development Services, pp. 38–39.

Podchezertseva, E.Yu. (2005). Justification of necessity for waste sorting as one of the stages in waste neutralization // In: *Proceedings of 4th International Scientific and Practical Conference of Students, Postgraduate Students and Young Scientists "Ecology and Scientific and Technical Progress"*. Perm: Perm State Technical University.

Veprentsev, I.V. (2006). European approach to waste management. *Municipal Solid Waste*, 10, pp. 34–36.

DOI: 10.23968/2500-0055-2018-3-3-51-56

STUDY ON THE EFFICIENCY IN SETTING UP A MOBILE VEHICLE INSPECTION STATION

Sergey Repin[1], Vladimir Golovko[2], Sergey Evtyukov[3]

[1,2,3] Saint Petersburg State University of Architecture and Civil Engineering
2-ya Krasnoarmeiskaya st., 4, St. Petersburg, Russia

[1] repinserge@mail.ru

Abstract

The paper analyzes the commercial feasibility of setting up mobile stations to provide people living in hard-to-reach areas with a service of state technical inspection (STI). An analysis of the application efficiency is carried out under conditions of significant territorial dispersion of sites to check the vehicle technical status in the Komi Republic. The rationale behind the efficiency can be expressed through a rate-of-return chart and results of the feasibility study on the operation of a mobile state technical inspection station, carried out in the Mathcad environment. Recommendations are given to reduce the costs and increase the profit from carrying out STI under specific competitive market conditions.

Keywords

Revenue, costs, rate of return, mobile station.

Introduction

State technical inspection (STI) allows improving significantly the technical condition of vehicles, reducing thereby the chance of road accidents. However, under conditions of significant territorial dispersion of sites to check vehicle technical status, for example, in the Komi Republic and in other regions of the Far North of the Russian Federation, it is difficult to provide the public with a service of STI (Caron, Mills, 2012; Zeng, Zhang, 2009). One way to solve this issue deals with setting up a mobile STI station. The rationale for the commercial feasibility in setting up those facilities is given in the article.

One of the recently developed methods of economic research, i.e. the marginal analysis, was used to analyze the efficiency of mobile STI stations; this analysis allows presenting results of commercial activity in a visual format and enables managers having no special education to take economically-balanced decisions on the company development.

Let us consider the terms used throughout the paper.

Mobile STI station

The mobile station (MS) to hold state technical inspection (STI)[1] is designed to provide services to owners of private cars and to companies on carrying out instrumental state technical inspection and generating a documented opinion on the technical status of vehicles under conditions of significant territorial dispersion of sites to inspect vehicles (Rubin et al., 2019). This situation is typical for regions having low population density, for example, for the Komi Republic, when it is economically inexpedient to set up stationary STI stations in small

[1] MS + STI = MSSTI

settlements, and car owners have to spend a lot of time to reach a site of obligatory technical inspection.

Efficiency. In the general case, efficiency is considered as a ratio of the operating result to the amount of resources consumed. From the economic standpoint, the efficiency indicator can be expressed through the rate-of-return level that is determined as the percentage ratio of the profit generated by sales of products to the production cost[2]:

$$R = \frac{SP}{C} \cdot 100, \quad (1)$$

where R — rate-of-return level, %; SP — sales profit (RUB); C — production cost (RUB).

Marginal analysis (MA) is an analysis of the ratio of the volume of products manufactured (services rendered) to the production cost and profit on the basis of forecasting the level of those values under given constraints (Azriliyan, 2004). The term "marginal" comes from the word "margin", which, in our case, represents the difference between the price and the cost of the service provided.

Main part

The margin analysis deals with dividing costs into *fixed* (or, more precisely, into semi-fixed costs as their value depends on the service life of the production equipment) and *variable costs. Fixed costs* are costs, the total amount of which does not change when the volume of products or the scope of services is altered. This group includes the following: depreciation of fixed assets; salaries and wages; depreciation of intangible assets; rent; expenses on maintaining buildings, premises; services provided by third parties; expenses on personnel training and development; expenses having a non-capital nature dealing with technology improvement and production management; deductions to the repair fund; deductions for compulsory insurance of property and other types of expenses. A significant part of semi-fixed costs comprising the machine-hour cost of equipment operation is expressed in the form of overheads. These costs actually represent production asset *ownership costs.*

The total of *variable costs* changes proportionally to the volume of the output product or to the scope of services rendered. This group includes the following: transportation costs, expenses on maintenance and repair of production equipment, fuel and lubricants, power consumed in production processes (Ratheesh, Vetrivelan, 2019).

The main category of the marginal analysis deals with the *marginal profit* which is represented by a difference between the income from selling company products and variable costs. The income implies proceeds received by an enterprise from selling products (without VAT).

The equation of the enterprise gross marginal profit consists of two main indicators: sales proceeds and variable costs. Below is an equation to calculate the efficiency of the whole enterprise (Zhdanov, 2015):

$$\textit{Marginal profit} = \textit{Revenue} - \textit{Variable costs} \quad (2)$$

In addition to calculating the marginal profit/income for the whole production volume, the marginal profit should be estimated for each product type. The marginal profit for each product type is calculated as a difference between the sales/distribution price and its production cost:

Marginal profit for the product type = Price –
–Production cost (3)

The calculation of the marginal profit for each product type makes it possible to exclude economically unprofitable products (Dotzler et al., 2018).

Let us consider Figure 1 to better understand the place occupied by the marginal profit in the enterprise profit system. The marginal profit is the second most important parameter following the sales proceeds (without VAT); the value of the marginal profit directly affects the size of operating and net profit.

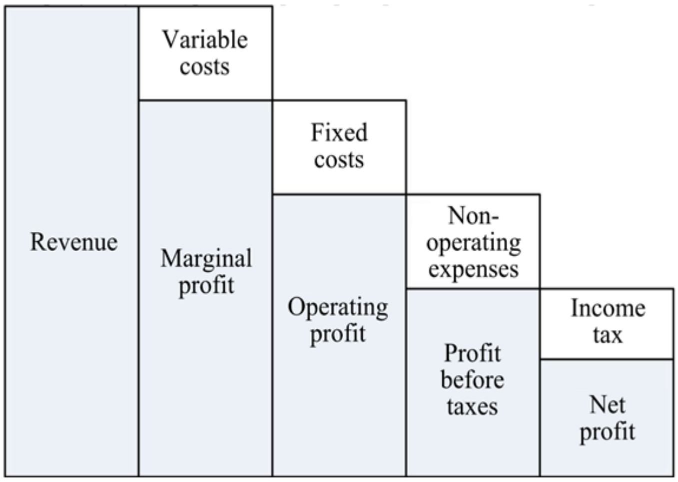


Figure 1. Enterprise profit structure (Zhdanov, 2015)

The analysis of the marginal profit involves resolving the following issues:

1. minimum allowable prices to distribute products (render services) at a given production volume and variable and fixed costs;
2. estimating the break-even volume of products manufactured (services rendered);
3. determining the profitability/unprofitability area;
4. forecasting the profit for different volumes of products sold (services rendered).

In the framework of this paper, we shall restrict ourselves with calculating the operating profit (which is the same as the sales profit, hereinafter — the profit) (Figure 2).

According to our calculations, the feasibility of setting up MSSTI will be hinged on reaching the minimum rate-of-return level (equation (1)) equal to 40%. It is clear that the rate-of-return level is defined by the volume of sales (N) and the ratio of the product price (Pr) and its production cost (PC). As follows from the profit generation scheme (see Figure 2):

$$\mathrm{Rev} = \mathrm{Rev} \cdot \mathrm{VAT} + \mathrm{C} + \mathrm{SP} \text{ or } \mathrm{SP} = \mathrm{Rev}\,(1\text{-}\mathrm{VAT}) - \mathrm{C} \quad (4)$$

[2] In the case considered, production means the number of conducted STI sessions.

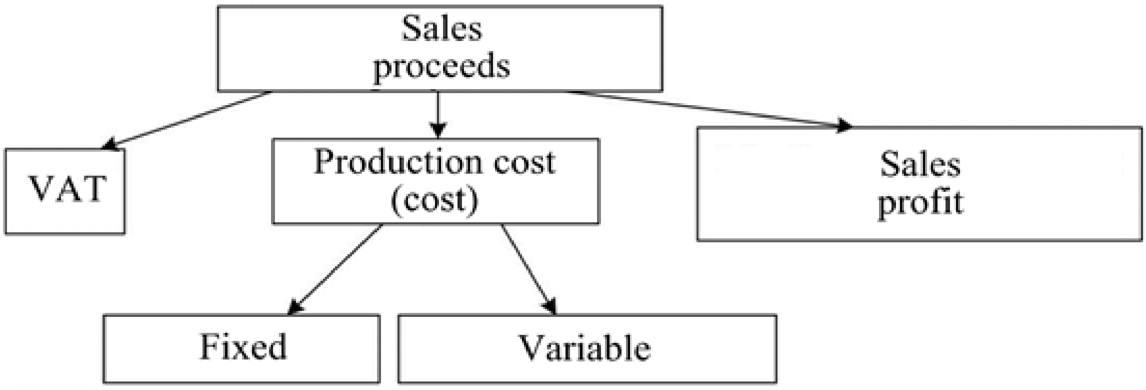


Figure 2. A profit generation scheme

where *Rev* is revenue generated by selling products. Hereinafter, we will not show the multiplier (1-VAT) implying that VAT is considered in equations of income calculation.

Substituting $\mathrm{SP} = \mathrm{C} \cdot \mathrm{R}$ and bearing in mind that:

$$\mathrm{Rev} = \mathrm{Pr} \cdot N \text{ and } \mathrm{C} = PC \cdot N \quad (5)$$

through simple transformations we obtain the required minimum price to make selling products profitable:

$$\mathrm{Pr} = \mathrm{PC} \cdot \frac{1+\mathrm{R}}{1-\mathrm{VAT}} \quad (6)$$

As it was mentioned above, the total costs C include fixed (Cfix) and variable (Cvar) costs:

$$\mathrm{C} = \mathrm{Cfix} + \mathrm{Cvar} \quad (7)$$

and provide the basis to calculate the production cost (equation (5)).

Dividing costs into fixed and variable ones allows showing the relationship between the revenue from selling products, production cost and the amount of profit generated by sales. This dependence of the profit of sales is expressed through a rate-of-return chart (Figure 3).

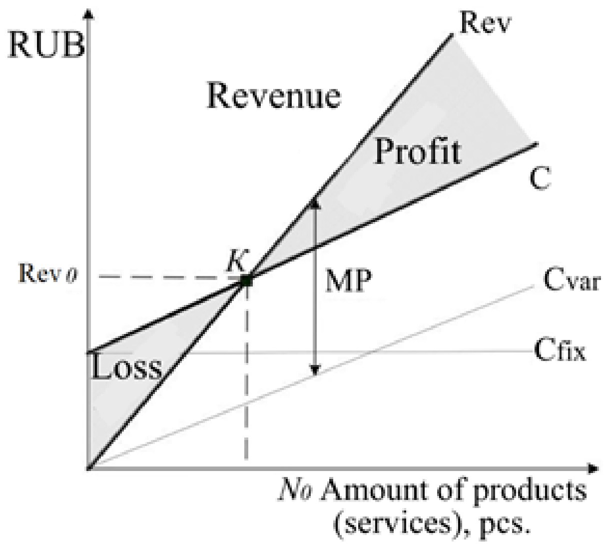


Figure 3. A rate-of-return chart: *K* — break-even point: Rev_0 = *C*, indicates the scope of N_0 services rendered (products manufactured) to make up for the company's gross costs (Rev_0 is the threshold revenue, N_0 is the threshold amount of products, MP is the marginal profit

The *K* point in Figure 3 is a break-even point; it shows the minimum revenue generated by selling products, below which the business activity is unprofitable since the production cost line is above the revenue line.

It should be noted that the difference in the slopes of the revenue (*Rev*) and costs (*C*) lines is determined by the difference in the price and cost of machine-hour (margin).

The marginal analysis of using MSSTI was carried out in the Mathcad environment (Figures 4, 5) using conditions of the Komi Republic as an example for the following initial data:

- mobile laboratory at the cost of 2,786,000 RUB (with equipment);
- estimated lifetime of the mobile laboratory — 8 years;
- annual mileage — 7,500 km;
- Value Added Tax – 18%;
- number of operators — 2;
- operator salary with charges and taxes — 44,000 RUB;
- standard time to complete STI of a passenger car — 0.76 hours;
- factor of MSSTI loading during working hours with account for the customers' waiting time — 0.78.

The initial data were obtained as a result of MSSTI pilot operation in the Komi Republic in (Golovko, 2012). The result of calculations showed 44% MSSTI rate of return.

As mentioned above, these results were obtained based on the calculations using the data on MSSTI pilot operation in the Komi Republic in 2012. In a competitive environment, it is important to be able to run a flexible pricing policy affecting the basic profit generation elements. Those involve the following: the service price, the number of services provided during the reporting period, components of fixed and variable costs.

In economics, the impact of relative changes in components on the profit is estimated through *elasticity* showing the percentage growth of the function, corresponding to increasing the argument by 1%. Let us consider the indicator for the mentioned basic elements.

Increasing the service price is the most attractive way to increase the profit. At the same time, the upper price limit is restricted by market conditions, and sometimes by the effective legislation (Luo et al., 2018).

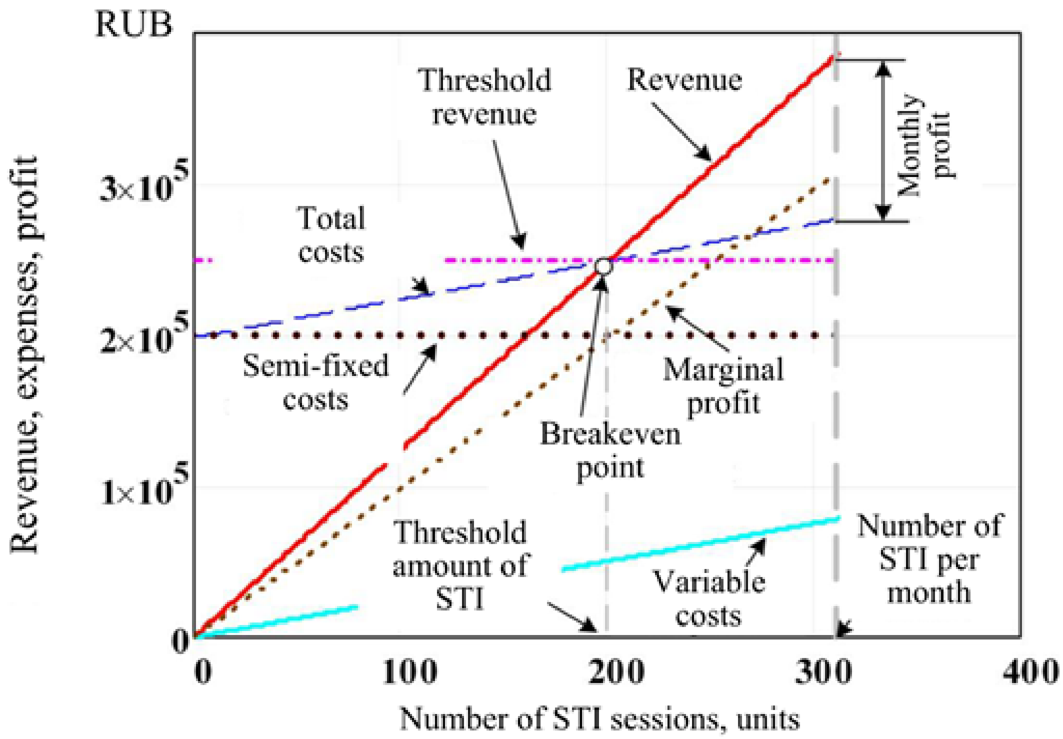


Figure 4. Results of the marginal analysis of MSSTI operation obtained in the Mathcad environment at the service price of 1,050 RUB

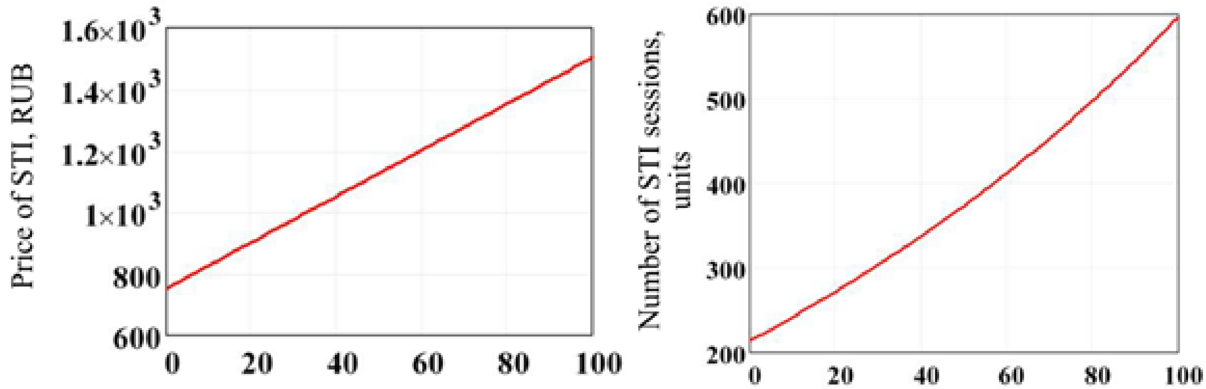


Figure 5. A dependence of the STI price (a) and the number of STI sessions (b) conducted at C = 1,050 RUB of the given rate-of-return level, calculated in the Mathcad environment

The price can be increased through expanding the list of services. For example, during STI, it is possible to issue an insurance policy or, if there is a slowdown in the flow of customers, undertake additional diagnostic, corrective maintenance and/or minor repair operations. Large companies often use decreasing product prices to strengthen their market positions which ultimately allow increasing the sales volume.

Increasing the number of STI sessions is possible through improving STI conduction (for example, getting paperwork done simultaneously with rendering technical services), reducing the customers' waiting time due to timely campaigns, improving the travel routes and choosing sites for MSSTI, etc.

Semi-fixed costs can be reduced through decreasing their components. Such decreasing is most effective when applied to overhead costs. In practice, this can be achieved through improving enterprise management, expanding the list of services provided, etc. In extreme cases, companies resort to such unpopular measure as reducing salaries and wages (Hament, Oh, 2018).

Reducing the variable cost component is possible through savings on the consumption of fuel and lubricants and improving the maintenance efficiency. When analyzing the composition of variable costs, the most effective option seems to be associated with bringing down the repair and maintenance costs.

Results of elasticity calculations are given in Table 1. The greatest influence on the profit is exerted by the following revenue components: the STI price and quantity. Fixed costs have a greater weight in the cost structure; therefore, they affect the profit value more.

DOI: 10.23968/2500-0055-2018-3-3-51-56

Table 1. Value of profit elasticity relative to arguments

Function	Argument			
	Semi-fixed costs	Variable costs	Scope of services	Service price
Profit	– 1.6	– 0,7	2.6	3.3

Conclusion

The research results provided in the paper give a positive estimate for the economic feasibility of setting up mobile technical inspection stations. The marginal analysis methods were used to determine the limits of the economic efficiency in using STI stations, expressed through the number of STI sessions and the service price.

References

Azriliyan A.N. (2004). *Bol'shoj ehkonomicheskij slovar' [Large economic dictionary].* Moscow: Institute of New Economics. (in Russian)

Caron, M., Mills, I. (2012). Planning and execution of tele-robotic maintenance operations on the ISS. In: *Proceedings of 12th International Conference on Space Operations*. Stockholm, Sweden. DOI: 10.2514/6.2012-1272635.

Dotzler, C., Botzler, S., Kierdorf, D., Lang, W. (2018). Methods for optimising energy efficiency and renovation processes of complex public properties. *Energy and Buildings*, 164, pp. 254–265. DOI: 10.1016/j.enbuild.2017.12.060

Frangopol, D.M., Liu, M. (2007). Maintenance and management of civil infrastructure based on condition, safety, optimization, and life-cycle cost. *Structure and Infrastructure Engineering*, 3 (1), pp. 29–41. DOI: 10.1080/15732470500253164

Golovko, V.A. (2012). *Razrabotka proekta uchastka avtoservisa dlya okazaniya uslugi po podgotovke prohozhdeniya GTO na baze OOO "VeGo"* [*Developing a service station project to prepare vehicles for STI at the premises of OOO VeGo].* Syktyvkar: Saint Petersburg State University of Service and Economics, Syktyvkar Branch. (in Russian)

Hament, B., Oh, P. (2018). Unmanned aerial and ground vehicle (UAV-UGV) system prototype for civil infrastructure missions. In: *Proceedings of IEEE International Conference on Consumer Electronics*, ICCE 2018, pp. 1–4. DOI: 10.1109/ICCE.2018.8326346

Luo, W., Li, L., Wang, K.C.P. (2018). Automatic horizontal curve identification and measurement using mobile mapping system. *Journal of Surveying Engineering*, 144 (4), 04018007. DOI: 10.1061/(ASCE)SU.1943-5428.0000257.

Ratheesh, R., Vetrivelan, P. (2019). Optimal energy saving through joint deployment of relay station and sleep mode activation in 4G LTE-A network. *Lecture Notes in Electrical Engineering,* 493, pp. 1–12. DOI: 10.1007/978-981-10-8663-2_1.

Rubin, I., Baiocchi, A., Sunyoto, Y., Turcanu, I. (2019). Traffic Management and Networking for Autonomous Vehicular Highway Systems. *Ad Hoc Networks*, 83, pp. 125–148. DOI: 10.1016/j.adhoc.2018.08.018

Zeng, W., Zhang, Z. (2009). Urban drainage network analysis based on GIS. In: *Proc. of International Conference on Pipelines and Trenchless Technology "Advances and Experiences with Pipelines and Trenchless Technology for Water, Sewer, Gas, and Oil Applications"*, 361, pp. 568–580. DOI: 10.1061/41073(361)61

Zhdanov I.A. *Marzhinal'naya pribyl' [Marginal profit]*. Available at: http://finzz.ru/base_knowledge/financial-analysis. (accessed on: 12.06.2018) (in Russian)