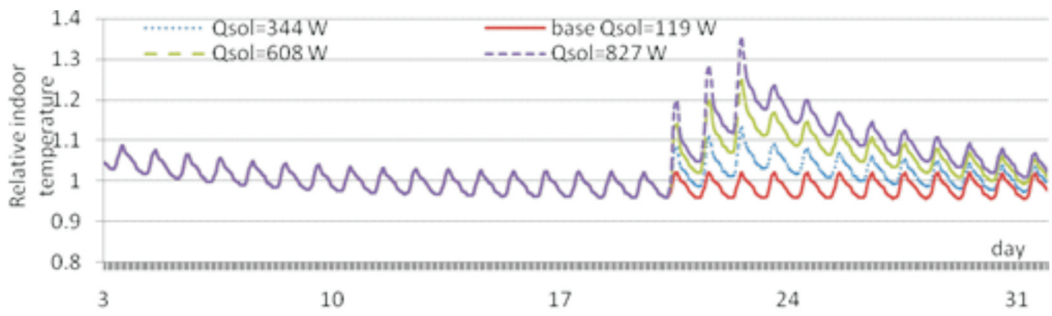
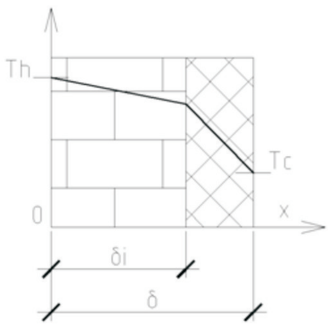
ISSN 2071-4726
2071-0305

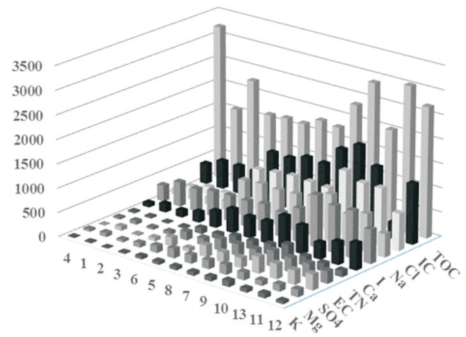
Инженерно-строительный журнал

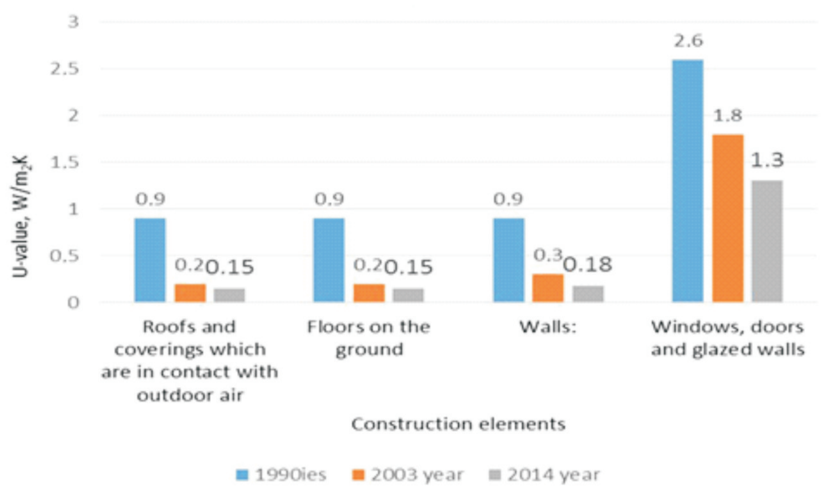
НАУЧНОЕ ИЗДАНИЕ

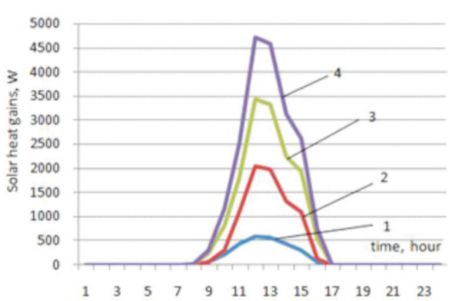
№8(68) 2016

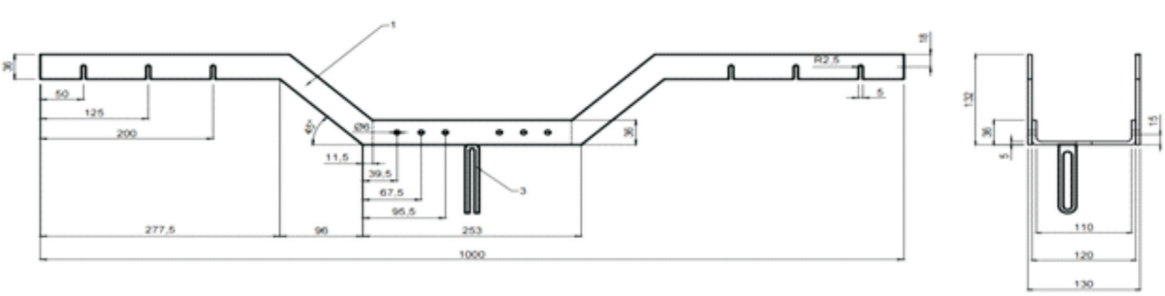


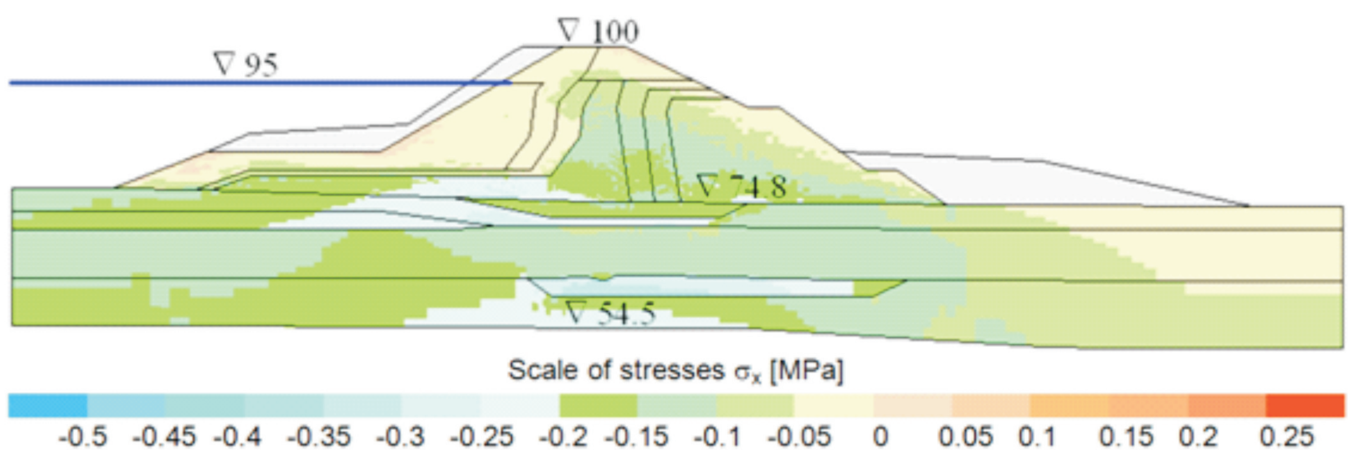












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БС-13	«Безопасность и качество выполнения гидротехнических, водолазных работ»	**30**
БС-14	«Безопасность и качество устройства промышленных печей и дымовых труб»	**31**
БС-15	«Осуществление строительного контроля»	**32**
БС-16	«Организация строительства, реконструкции и капитального ремонта. Выполнение функций технического заказчика и генерального подрядчика»	**33**
	Курсы по проектированию	
БП-01	«Разработка схемы планировочной организации земельного участка, архитектурных решений, мероприятий по обеспечению доступа маломобильных групп населения»	**1,2,11**
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БП-11	«Организация проектных работ. Выполнение функций генерального проектировщика»	**13**
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И-05	«Организация работ по инженерным изысканиям»	**7**

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Инженерно-строительный журнал
НАУЧНОЕ ИЗДАНИЕ

ISSN 2071-4726

Свидетельство о государственной регистрации: ПИ №ФС77-38070, выдано Роскомнадзором

Специализированный научный журнал. Выходит с 09.2008.

Включен в Перечень ведущих периодических изданий ВАК РФ

Периодичность: 8 раз в год

Учредитель и издатель:

Санкт-Петербургский политехнический университет Петра Великого

Адрес редакции:

195251, СПб, ул. Политехническая, д. 29, Гидрокорпус-2, ауд. 227А

Содержание

На обложке: иллюстрации авторов к статьям номера

Установочный тираж 1000 экз.

Подписано в печать 25.04.2017. Формат 60х84/8, усл. печ. л. 11,5. Заказ № 0943.

Отпечатано в типографии СПбПУ. СПб, ул. Политехническая, д. 29

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Web: http://www.engstroy.spbstu.ru

http://www.engstroy.spbstu.ru – full-text open-access version in Internet. It is updated immediately with each new issue.

Magazine of Civil Engineering
SCHOLAR JOURNAL

ISSN 2071-4726

Peer-reviewed scientific journal

Start date: 2008/09

8 issues per year

Publisher:

Peter the Great St. Petersburg Polytechnic University

Indexing:

Scopus, Russian Science Citation Index (WoS), Compendex, DOAJ, EBSCO, Google Academia, Index Copernicus, ProQuest, Ulrich's Serials Analysis System

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Contents

On the cover: authors' illustrations

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doi: 10.5862/MCE.68.1

Stress-strain state of seepage-control wall constructed for repairs of earth rock-fill dam

Напряженно-деформированное состояние противофильтрационной стены, выполненной для ремонта каменно-земляной плотины

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Key words: earth-rockfill dam; cut-off wall; dam failure; soil subsidence; stress-strain state; clay-cement concrete; seepage load; bored piles

Ключевые слова: каменно-земляная плотина; стена в грунте; авария плотины; просадки грунта; напряжённо-деформированное состояние; глиноцементобетон; фильтрационная нагрузка; буронабивные сваи

Abstract. Methodology and the results of numerical modeling of stress-strain state (SSS) of an earth-rockfill dam are considered, where after a failure of the clay core there was created a new seepage-control element presented by a clay-cement concrete wall. Calculations were conducted on the example of the dam section of Kureyka HPP, where emergency situation occurred in 1992. For repairs of the 25 high dam in the core and in the foundation there was arranged a 35 m deep wall made of bored piles. SSS analyses of the dam were conducted with use of the computer program elaborated by the author. This permitted consideration in the analyses of a number of important factors such as the sequence of the dam and the wall construction, non-linearity of soils deformation, their subsidence as well as time-dependent variation of seepage forces. Seepage calculations showed that load on the piles from seepage flow is formed over a long time due to the durable process of the wall construction. If piles are arranged sequentially, one pile after another, during this time clay-cement concrete acquires about 50 % of design strength. If the wall is constructed in 2 stages, clay-cement concrete acquires about 80 % of its strength. SSS analyses showed that the wall in the failed dam performs in complicated conditions: due to a non-uniform structure of soil mass, it is subject to complicated bending deformations. To avoid the appearance of tensile stresses in the wall it is recommended to make the wall of plastic clay-cement concrete whose deformation is close to deformation of soils.

Аннотация. Рассматриваются методика и результаты численного моделирования напряжённо-деформированного состояния (НДС) каменно-земляной плотины, в которой после выхода из строя её глинистого ядра устроен новый противофильтрационный элемент – стена из глиноцементобетона. Расчёты проводились на примере участка плотины Курейской ГЭС, аварийная ситуация на котором произошла в 1992 году. Для ремонта плотины высотой 25 м в ядре и основании была устроена стена глубиной 35 м из буронабивных свай. Исследования НДС плотины проводились с помощью вычислительной программы, составленной автором. Это позволило учесть в расчётах ряд важных факторов, таких как последовательность возведения плотины и стены, нелинейность деформирования грунтов, их просадки, а также изменение во времени фильтрационных сил. Фильтрационные расчёты показали, что нагрузка на сваи от фильтрационного потока формируется длительное время из-за продолжительного технологического процесса возведения стены. Если сваи устраиваются последовательно, свая за сваей, то за это время глиноцементобетон успеет набрать около 50 % проектной прочности. Если стена возводится в 2 очереди, то глиноцементобетон набирает уже около 80 % своей прочности. Расчёты НДС показали, что стена в аварийной плотине работает в непростых условиях – из-за неоднородного строения грунтового массива она испытывает сложные изгибные деформации. Во

Саинов М.П., Анисимов О.В. Напряженно-деформированное состояние противофильтрационной стены, выполненной для ремонта каменно-земляной плотины // Инженерно-строительный журнал. 2016. № 8(68). С. 3–17.

избежание появления в стене растягивающих напряжений рекомендуется выполнять стену из пластичного глиноцементобетона, деформируемость которого близка к деформируемости грунтов.

Introduction

Structures like the “cutoff wall” started to be used as seepage control curtains in the middle of the XX-th century. Recently seepage control arrangements of this type were broadly used for seepage control in the dam foundation. The examples may be Yumaguza [1], Gotsatlin (Russia) and Sangtuga (Tajikistan) [2] dams, dams Karkheh (Iran) [3], Peribonka (Canada) [4], Merowe (Sudan) [5], Dhauliganga (India) [7] and others [6, 8, 9]. Seepage-control walls were also arranged as diaphragms of earthfill dams [10].

One more important use of structures like “slurry trench cutoff wall” was their application for repairs of earthfill dams. For example, a 70 m deep wall was arranged in the foundation of Sylvenstein dam during its reconstruction [11].

At repairs of earthfill dams, the arrangement of a new seepage-control element sometimes is required not in the dam foundation but inside the dam. The thing is that at a number of earth rock-fill dams there have occurred emergency situations when the seepage-control element failed. The examples may be dams Balderhead (Great Britain) [12], Hyttejuvet (Canada) [13], Kolyma and Kureyka [14] dams (Russia). Through joints were formed in clay cores of these dams which became paths of intensive seepage. This seepage resulted in intensive scour by seepage flow of the dam body and soil removal beyond the dam profile. Further development of seepage deformations may result in full dam failure unless emergency and repair measures have been taken.

Heavy overhaul of damaged earth rock-fill dams may be carried out using two main methods. The first one envisages repairs of soil seepage-control element by filling joints developed in it with different mortars. The second, more reliable method suggests arrangement in the dam body of a new seepage-control element. Such seepage-control element is usually presented by seepage-control walls constructed by a “cutoff wall” method. The first seepage-control wall was arranged in 1968 for repairs of Balderhead dam [12].

A new seepage-control element has to work in complicated conditions because the density of the enclosing it soil was disturbed during failure. This article deals with studies of operation conditions of the seepage-control wall arranged in the body of the failed earth rock-fill dam as well as the effect of these conditions on the wall safety.

The study was conducted on the example of Kureyka HPP dam. Kureyka HPP earth rock-fill dam was constructed in 1980-s on the Kureyka River in Russia’s Far North [14].

The emergency situation at Kureyka dam occurred on July 26, 1992, at its left-bank section. During failure the upstream level was 95 m, 0.5 m higher than FSL. The length of the emergency section was about 30 m (from Sta. 7+00 to Sta. 7+32). The emergency situation was created due to the sharp increase of seepage discharge (from 20 to 1750 l/s), removal by seepage flow of a considerable volume of soil, as well as subsidence of the dam upstream slope crest. Crest subsidence at the dam emergency section amounted to about 1 m [14, 15].

As a mitigation measure the clay soil was filled in the upstream slope and at the downstream slope, a stone drain was arranged with surcharging by gravel-pebble soil.

By the flood period of 1993 the repairs on the dam had been fulfilled, which consisted of injection of cement-clay mortars [16]. At drilling operations, disturbances in core integrity were revealed. There were observed sections with liquid loam as well as sections filled with sand and gravel. Three water permeable zones were found in the structure, which created through seepage paths (Fig. 1). Two zones were located in the dam core: the upper zone was approximately in the middle of the core height ($\nabla 81 \div 83$ m), the lower zone was at its toe ($\nabla 76 \div 80$ m). The third permeable zone does not cross the core. The beginning of this zone was located vertically and separated the core from the upstream apron. Through this joint water ingressed in the foundation sand interlayer under the core and through it bypassed the seepage-control element of the dam. Evidently, development of the emergency situation started from this particular zone, and located above water permeable zones were formed later as a result of the emergency situation development.

Sainov M.P., Anisimov O.V. Stress-strain state of seepage-control wall constructed for repairs of earth rock-fill dam. *Magazine of Civil Engineering.* 2016. No. 8. Pp. 3–17. doi: 10.5862/MCE.68.1

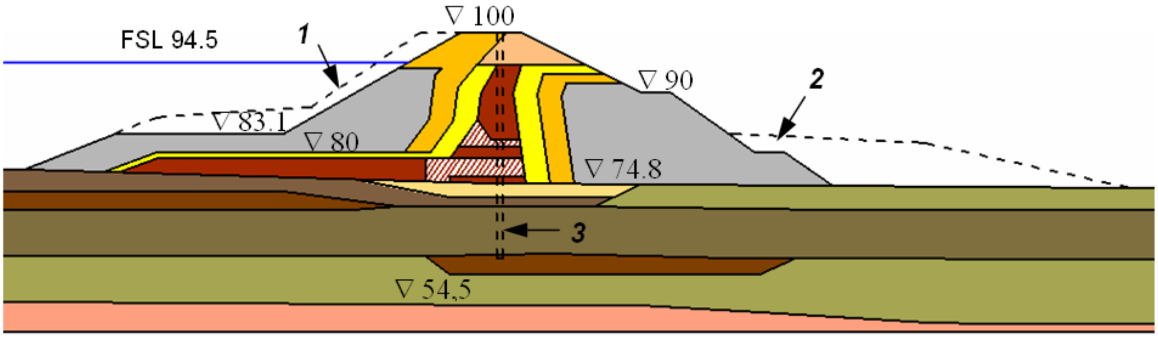

Figure 1. Dam configuration in the design section (Sta. 7+27)
1 – profile of fill on the upstream slope for emergency situation liquidation; 2 – profile of fill on the downstream slope; 3 – location of the seepage-control wall made for dam repairs

Color designations of the dam body and foundation materials:

П-1 – loam of the core and the apron in the intact state; П-2 – disturbed zone in the dam core; П-3 – soil of the first layer of transition zones; П-4 – soil of the second layer of transition zones; П-5 – rock muck of the dam shells; П-6 – gravel-pebble soil on the dam crest; О-1 – foundation sand; О-2 – rock foundation; О-3 – foundation loam; О-4 – foundation sandy loam; О-5 – foundation gravel-pebble soil with loam filler; О-6 – foundation gravel-pebble soil with sandy loam filler

Considerable damage of the dam core and foundation made their rehabilitation impossible without the reservoir drawdown, therefore, it was decided to make repairs by arranging a new non-soil seepage-control element.

The design of measures on repairs of the dam emergency section envisaged construction of a wall at the section from Sta. 6+20 to Sta. 7+60. The wall was made of bored piles 1200 mm in diameter with spacing 850 mm [17, 18]. The design depth of the wall is 35 m. It cuts the about 25 m high earthfill dam body and deepens into the earth foundation for about 10 m.

For the seepage-control wall material there was used liquid plastic clay-cement concrete consisting of 125–156 kg of Portland cement and 120–140 kg of bentonite, 380–680 kg of sand and 900–1000 kg of gravel [18, 19]. The density of this material is 1.98–2.26 kg/m^3. This clay-cement concrete has a cube uniaxial compression strength 1–2 MPa. However, its strength properties are rather unstable, and the process of gaining strength is rather durable (Table 1) [18, 19]. Over the first 7 days is gains approximately 50 % of strength at the age of 28 days. The maturing process also continues after 28 days.

Table 1. Compressive strength of clay-cement concrete samples

Age of samples	7 days	28 days	90 days
Strength minimum value, MPa	0.42	0.57	0.70
Strength average value, MPa	0.91	1.36	2.02
Strength maximum value, MPa	1.52	2.38	3.07

There is controversial information about deformability of clay-cement concrete. According to the data [18] the deformation modulus of clay-cement concrete is equal to 10–20 MPa, and according to the data [19] it is 30–200 MPa.

The wall was constructed in 1998–2000 and to date it has been working reliably. Our studies of Kureyka dam seepage-control wall workability should determine the degree of safety of this structure and reveal its determining factors.

Methods

Peculiar features of design studies methodology

Solution of the given assignment is rather complicated because SSS analysis should consider the complicated design scheme of the structure behavior: multiple important factors affecting its SSS.

The first factor is construction sequence of the structure and the wall itself. The seepage-control wall is constructed in the already existing earthfill dam, therefore, before solving the task about the dam behavior with the wall it is necessary to solve the problem of the dam SSS before construction of the wall. Besides, it is necessary to represent the process diagram of the wall construction. The methodology of the wall construction of bored piles envisages filling of piles with clay-cement concrete. Hardening of clay-cement concrete occurs already in the structure. Therefore, calculation should be carried out at least in two stages. The first stage refers to clay-cement concrete in non-hardened semi-liquid state. At this stage the wall SSS from its own dead weight is formed. At that, it is necessary to take into account that clay-cement concrete may freely settle under its own weight, because its shear strength is small. For this purpose in the design diagram it is necessary to envisage presence of a sliding contact between clay-cement concrete and soil. If this feature is not taken into account the wall stress state may be distorted due to the effect of clay-cement concrete “hanging” on the surrounding soil. The second stage of analysis is the behavior of wall of hardened clay-cement concrete. Perception by the wall of seepage forces may occur both on the first and the second stages depending on conditions of these forces formation.

The second factor is the value and conditions of formation of external forces acting on the wall and the whole structure. As loads on the seepage-control wall are formed by seepage flow in order to determine these loads it is necessary first to solve the problem of the structure seepage regime.

Before failure the dam core may be considered to be watertight, therefore, action of water corresponds to hydrostatic pressure. During failure, water permeable zones are formed; therefore, hydrostatic pressure in them should be replaced by seepage forces. For determining seepage forces it was necessary to solve the problem of seepage through water permeable zones. The obtained distribution of seepage flow levels is shown in Figure 2. Forces from seepage flow are distributed forces. Inside water permeable zones the seepage forces are distributed by volume. At water permeable boundaries of these zones the seepage forces are presented by surface forces from pressure of filtering water.

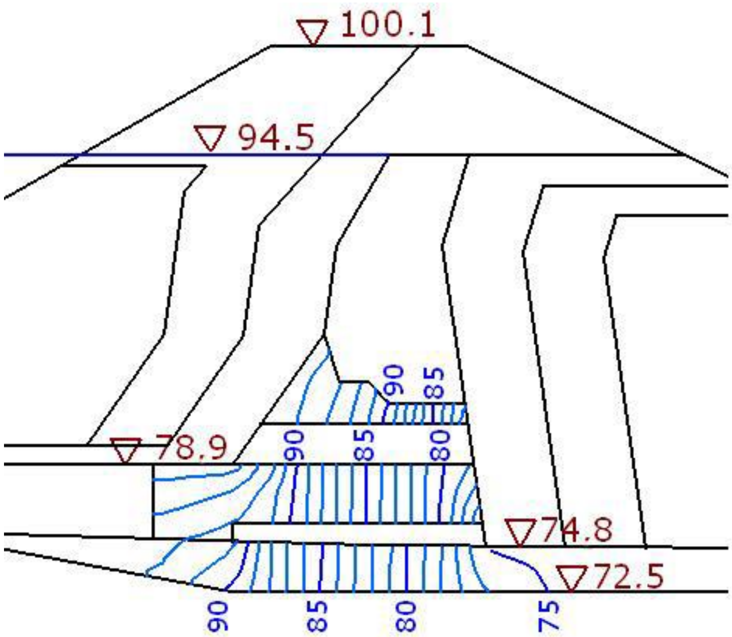

Figure 2. Location of lines of the equal level in water permeable zones of the structure during failure

Arrangement of the seepage-control wall in the dam cardinally changes the seepage pattern: seepage head is concentrated on the wall. However, variation of seepage flow occurs slowly, gradually. Therefore, conditions of the wall perception of seepage load depend on how fast this load will rise as compared to the process of clay-cement concrete maturing.

In order to determine the character of seepage load formation it is necessary to solve a 3D problem on unsteady seepage regime of the structure during construction of a watertight wall in it. This problem was solved by M.P. Sainov in his Ph. D. thesis. Studies showed that the value of seepage load on the pile depends on location of this pile within the wall. Seepage load on end piles is small because seepage flow bypasses the wall. The longer is the distance of the pile from the end of the wall the higher is seepage pressure which it perceives.

Investigations showed that formation of seepage load on the wall occurs rather quickly. Seepage pressure manages to acquire values typical for steady seepage regime due to low rate of the wall construction: 1–2 piles a day.

However, it should be taken into account that formation of seepage load starts from the moment when the wall becomes an entire barrier. Depending on the wall construction sequence the character of increase of seepage load on one bored pile may be different. As it is known in practice there may be used two sequences of construction of a bored piled wall: the first one when piles are arranged sequentially and the second when the wall is constructed in two stages (first-stage piles are arranged next but one, and then the second-stage piles fill the space between the first-stage piles).

Figure 3 shows time-dependent variation of water levels around one separate pile for two construction methods of the wall[1]. Water level from the pile upstream side rises, while from the downstream side it lowers.

When piles are arranged subsequently, the rate of seepage forces increase is determined by the rate of bored piles construction. At placement of one pile a day the pressure on the wall will increase faster than the rate of clay-cement concrete hardening (Fig. 3). When piles are arranged in 2 stages there appears the difference between operation conditions of the first-stage piles and the second-stage piles. The first-stage piles for durable time do not have loads from seepage flow, because it passes between them. Seepage pressure arises only when space between piles of the first stage is filled by the second-stage piles. During these several days clay-cement concrete may acquire 50–80 % of its strength. From the moment of the wall closure the pressure on piles of the first and the second stages starts to grow intensively (Fig. 3). This process is faster than that during subsequent construction.

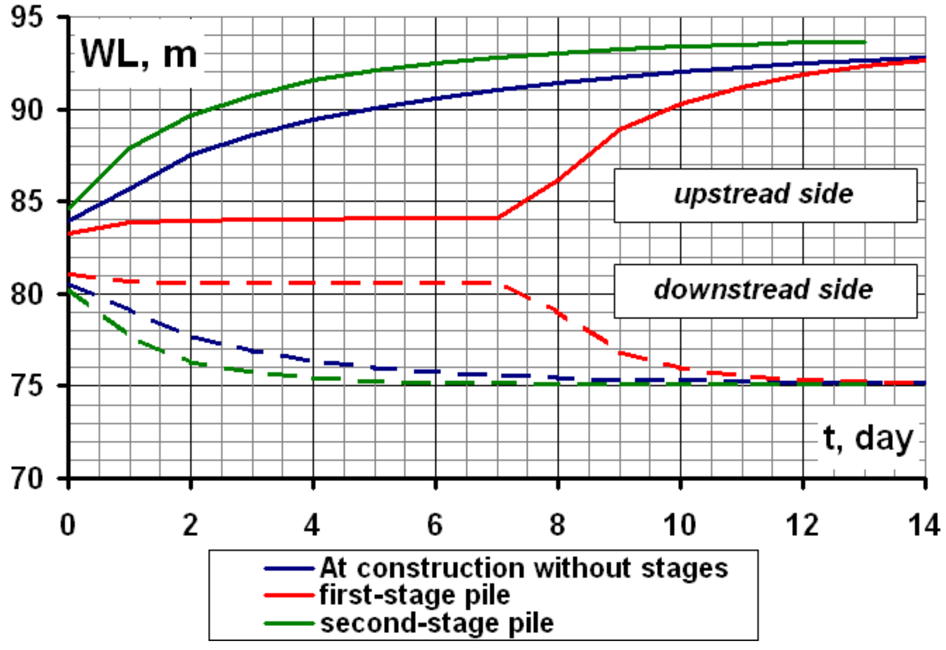

Figure 3. Variation of seepage water levels around a pile

Thus, the first-stage piles will perceive external forces at nearly hardened clay-cement concrete, but the second-stage piles at non-hardened clay-cement concrete. From the point of view of the stress state formation the first-stage piles are in worse conditions because at greater stiffness of material the greater stresses occur. The most dangerous case may be taken into account when seepage load is taken by a pile at hardened clay-cement concrete.

[1] At wall construction in 2 stages it was assumed that at each stage 7 pilles are placed.

The third factor is conditions of perceiving external forces by the dam and foundation. The peculiarity of considered problem is the fact that the seepage-control wall is constructed in the already operating dam. Even before the wall construction the dam already took loads from seepage flow, therefore, with wall arrangement the loads are redistributed, but new ones do not appear. Water pressure on the wall appears, but pressure on the core upstream face disappears.

This peculiarity is important from the point of view of an earthfill structure behavior. Soils have a pronounced non-linear character of deformation: the characteristic feature for them is development of both elastic and plastic deformations. Destressing is mainly characterized by elastic deformations, while at active loading there are both elastic and plastic deformations. As during construction of the wall in the dam no new loads appear but the existing ones are redistributed, the considered problem of the structure SSS should be solved only in elastic-plastic formulation.

The fourth factor is the necessity of considering the change in an earthfill dam state at development of emergency situation in it. First of all it is necessary to take into account the appearance of the zones in the dam which were weakened as a result of soil scouring by seepage flow. This may be considered by increase of their deformation. Secondly, it is necessary to model subsidence of the structure in emergency situation.

A special calculation procedure was worked out for consideration of subsidence. It was assumed that the cause of subsidence was not just a simple disturbance of soil structure, but soil failure due to loss of part of its volume. As the remaining part of soil volume has to take forces previously applied to the whole volume, it is subject to additional deformations. However, these deformations occur in conditions of material disturbance and the ormed cavities permit free deformations of soil, full reforming of soil structure takes place. One can say that subsidence is the process of forming new soil.

Based on this in the analysis it was adopted that in subsidence zones, SSS of soil mass newly forms. All internal forces previously present in them were minimized to zero and non-balanced by them external forces formed new SSS of the structure.

Consideration of all the aforementioned peculiarities of SSS formation of the dam with a seepage-control wall is a rather complicated task. The first approximate solution of this problem was described in [20]. Full consideration of all the peculiarities became possible due to creation and modernization by M.P. Sainov of a special computer program NDS-N [21]. For description of elastic-plastic behavior of soil it uses the soil elastic-plastic model proposed by L.N. Rasskazov [22], and updated by M.P. Sainov.

Numerical model of the structure

SSS analysis was conducted with use of numerical modeling. A numerical model of the structure based on finite element method was developed for solving this problem. A 25 m high dam section with a central core of complicated configuration was considered (Fig. 1). In this section the dam is located on 20 m thick soil foundation presented by interlayered pebbles, clays and sands.

The dam cross section and its foundation was divided into 722 finite elements. Out of this number 679 elements modeled the behavior of continuous medium and 43 the behavior of contacts between soils and the wall clay-cement concrete (Fig. 4). At finite element discretization of the structure the use was made of high-order finite elements with cubic approximation of displacements inside the element. This permitted obtaining smooth distribution of stresses inside constructions.

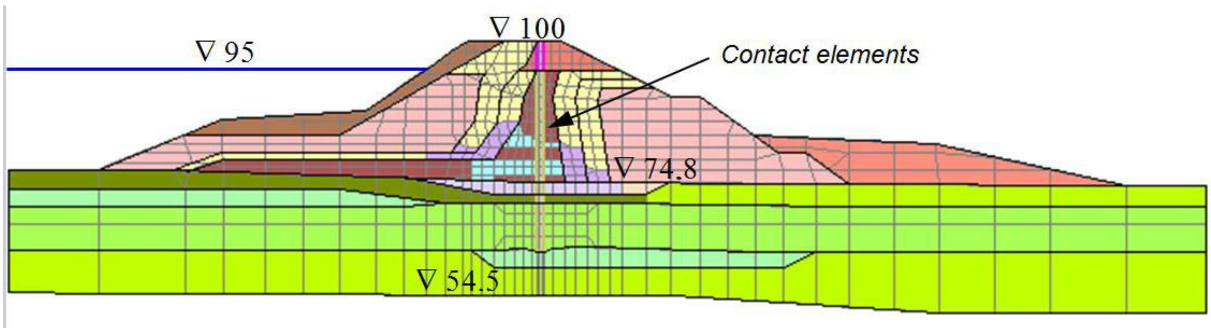

Figure 4. FEM mesh for the dam design section

Total number of degrees of freedom in the obtained numerical model amounted to 6801.

Conditions of the wall operation required considering in the structure model “the history” of its SSS formation. There were considered 26 computational steps where at each step the changes of structural design of the structure or acting on it external forces were modeled. Computational steps may be grouped in 5 characteristic stages of the structure operation.

At the first stage the foundation SSS due to its dead weight was modeled. At the second stage the computational domain SSS formation was modeled for the period of the earthfill dam construction. Gradual dam construction by horizontal layers was simulated. Twelve moments of time (steps) were modeled where at each step the dam profile rose upward. At the third stage the dam became a water retaining structure: reservoir hydrostatic pressure was applied to it. Six moments of time (steps) were considered where at each step the upstream water level gradually increased.

At the fourth computational stage the modeling was fulfilled of the structure SSS variation at appearance, development and liquidation in it of the emergency situation. At the first step of this stage the formation of water permeable zones was modeled: the character of water force action on the structure changed. Hydrostatic pressure on the core upstream face was replaced by seepage flow forces (spatially distributed seepage forces and seepage forces distributed on the surface). The second step modeled the failure itself, i.e. damage of the dam by seepage flow, when intensive seepage led to disturbance of soil structure and properties. In the structure model the zones were distinguished where soil subside and have increased deformation. They covered part of the core, transition zones as well as the sand layer in the dam foundation (Fig. 5b).

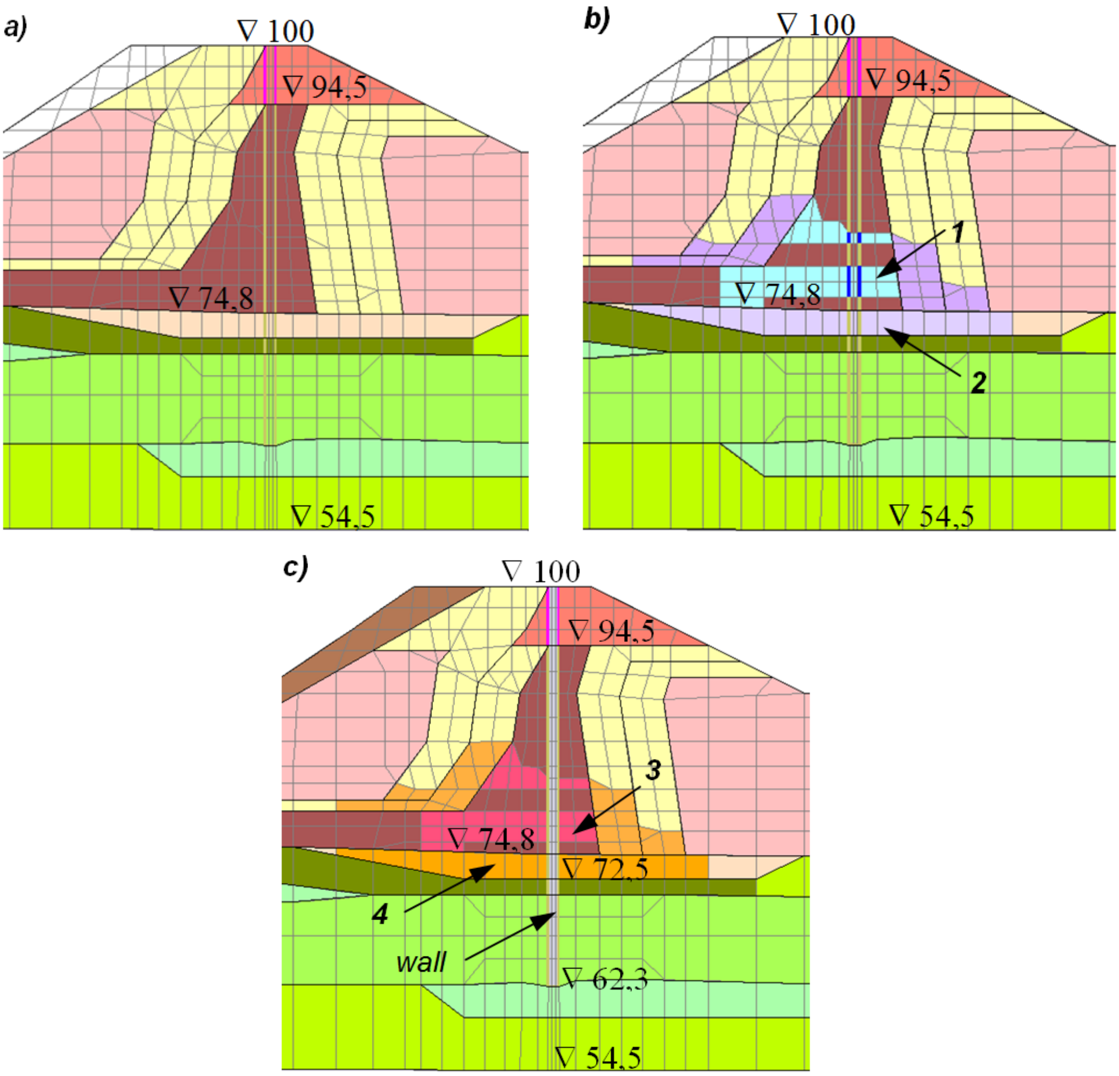

Figure 5. Changes in FEM mesh at various stages of computations (fragment)
a – before failure; b – during failure; c – after failure, at dam construction;
1, 2 – water permeable zones and zones of subsidence, 3, 4 – zones of weakened soils

At subsequent four steps of the fourth stage the emergency fill of soils on the dam slopes was modeled. On the upstream slope the clay fill was simulated, on the downstream slope the filling of filter.

The fifth stage of calculations modeled the structure operation clay-cement concrete diaphragm. This stage included computation for two time periods (steps). The first step simulated creation of the wall and its perception of its dead weight in conditions when clay-cement concrete has not yet hardened. The second step modeled perception by the wall of its external forces from filtering water. Loads on the wall were determined from solving the seepage problem. Above the dam toe the water pressure corresponded to the upstream hydrostatic pressure (Fig. 6). At computations of the second step it was assumed that by the moment of perceiving the external forces the clay-cement concrete will have already be hardened.

Deformation characteristics of soils were assumed by analogs with consideration of available data. Elastic-plastic model of soils was used.

Foundation soils were assumed to be linearly-deformed. Non-rigid characteristics of soils in soil foundation for the stage of active loading adopted in the calculation are given in Table 2.

At consideration of the dam body soils it was assumed that non-rigid characteristics depend on their stress and strength state.

Non-rigid characteristics of soils in the zones of subsidence were selected from condition of matching design dam subsidence values to field values. For soils of transition zones and the core the deformation moduli became 5 times less as compared to initial values and those of foundation sand were 6 times less.

At the stage after the failure non-rigid characteristics of soils in failure zones were taken with lower values than those which had been before the failure, because these soils have loose structure. Deformation modulus of soils was conditionally taken to be equal to half of the value which had been before the emergency situation.

For all soils the deformation modulus at loosening was taken by an order more than that at active loading.

In computations the wall material was assumed to be linearly-deformed, elastic, so that it could be possible to assess its strength state. Deformation modulus of clay-cement concrete was taken equal to 200 MPa, Poisson’s ratio 0.3.

For comparison the calculation was carried out where the wall material was reinforced concrete with deformation modulus E = 29000 MPa and Poisson’s ratio 0.18.

For the moment of the wall material placement into the pile in the calculation it was assumed that it had not yet hardened. Its deformation modulus was taken equal to 20 % of the final value and Poisson’s ratio was 0.45.

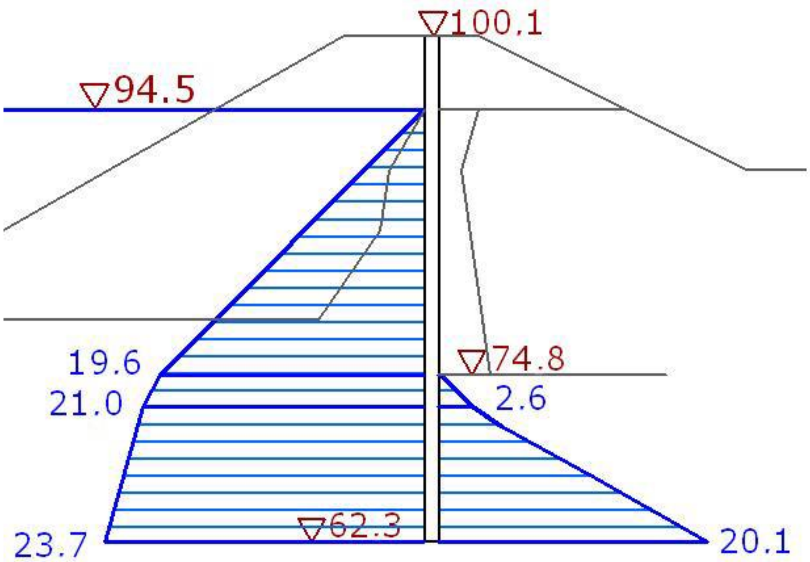

Figure 6. Design curve of seepage pressure on the pile (in m of water column)

Table 2. Design non-rigid characteristics of foundation soils

Type of soil	Deformation modulus, MPa	Poisson's ratio
Pebble with sandy loam filler	15	0.30
Pebble with loam filler	15	0.30
Sandy loam	10	0.40
Loam	8	0.40
Sand	6	0.33

Results and Discussion

By the results of computations the dam has complicated SSS. Before development of emergency situation the dam SSS was considerably subject to soil foundation deformations. Under the dam dead weight and hydrostatic pressure on the apron the dam foundation settles and expands in both sides (Fig. 7, 8). The greatest settlements (56 cm) of foundation occurred under the apron, near the core (Fig. 8). In this zone the dam settlements also reached the maximum values (60 cm). The core settlements are more considerable than those of the shells.

Maximum displacements also observed on the boundary between the dam and the foundation (Fig. 7). Under the upstream shell the settlements are directed toward the upstream side (maximum 14 cm). Under the downstream shell the settlements are directed toward the downstream side (16.3 cm). Settlements of shells in different directions may have resulted in separation of the apron from the core and development of a vertical joint at their contact.

By distribution of stresses σ_y in the dam body (Fig. 10) "suspension" of the core on the shells may be noticed. In the core foundation the stresses σ_y did not exceed 0.45 MPa, while in the downstream transition zone they reached 0.75 MPa. From the upstream side the core suspends weaker, because it has some inclination toward the upstream side. Deficit of compressive stresses σ_y in the core could also cause failure.

By horizontal stresses σ_x the core also was under compression (Fig. 9), however, their values (up to 0.2 MPa) were less than water pressure. At development of random cracks the disjoining hydrostatic pressure could result in hydraulic fracturing of the core especially in the zone of its contact with the apron.

At appearance in the core of water permeable zones the level of compression by stresses σ_x in the upstream part of the core decreased actually to 0. Due to hydrostatic effect of water the compressive stresses σ_y also decreased.

At modeling the dam failure it was assumed that the subsidence zone covers a part of the core, both transition zones as well as the sand layer under the dam (Fig. 5b). Figures 11, 12 show design displacements of the structure at development in it of subsidence zones as a result of soil damage by seepage flow.

By the results of computations the maximum values of subsidence occurred in the upstream transition zone (Fig. 12). They amounted to 103 cm. This may be explained by the fact that in this particular zone the soils were subject to the most intensive scour: water permeable zones appeared in the core, in the foundation sand layer, in the zone of the apron and the core conjugation (Fig. 1), besides, the transition zones were damaged. At the crest the design subsidence amounted to 95 cm, which corresponds to the actual data [14].

The subsidence zone covered all the central part of the dam: the core and the soils surrounding it (Fig. 12). Presence of subsidence zones led to displacement of the dam crest part toward the upstream transition zone. The crest tumbles down toward the upstream side. Displacements reached 46 cm. Vice versa, the weakened lower part of the core displaced toward the downstream side. These displacements were caused by seepage forces. Maximum displacement amounted to 19 cm.

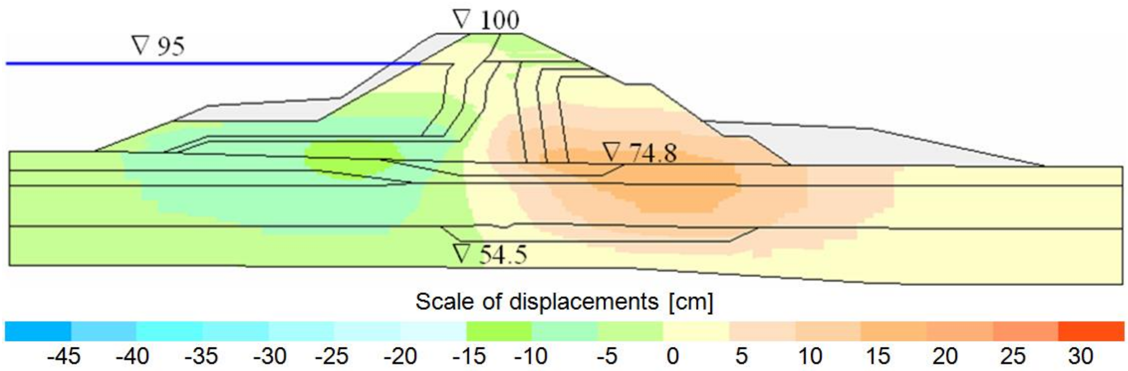

Figure 7. Structure horizontal displacements occurred during construction and reservoir filling

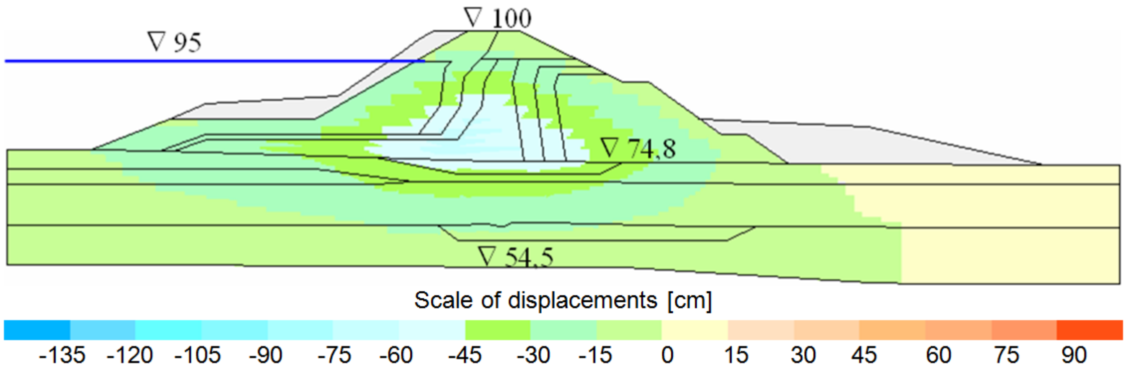

Figure 8. Structure vertical displacements occurred during construction and reservoir filling

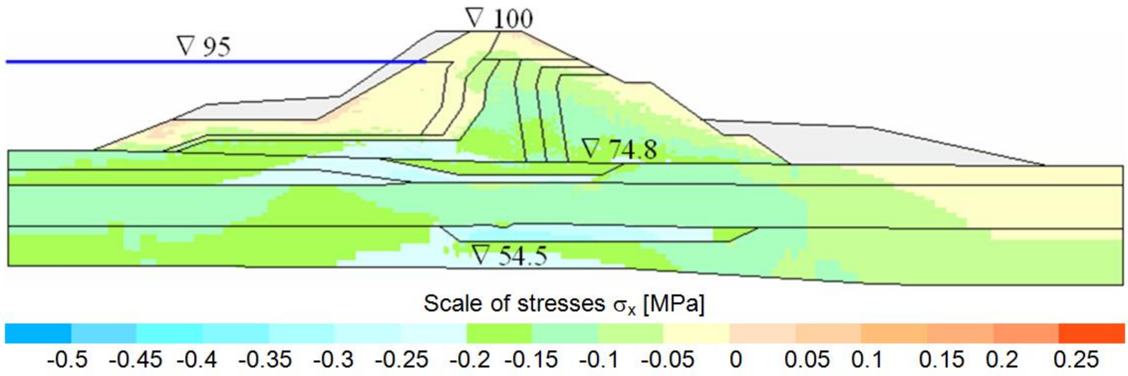

Figure 9. Horizontal stresses σy in the dam body and foundation for the moment of construction completion and reservoir filling

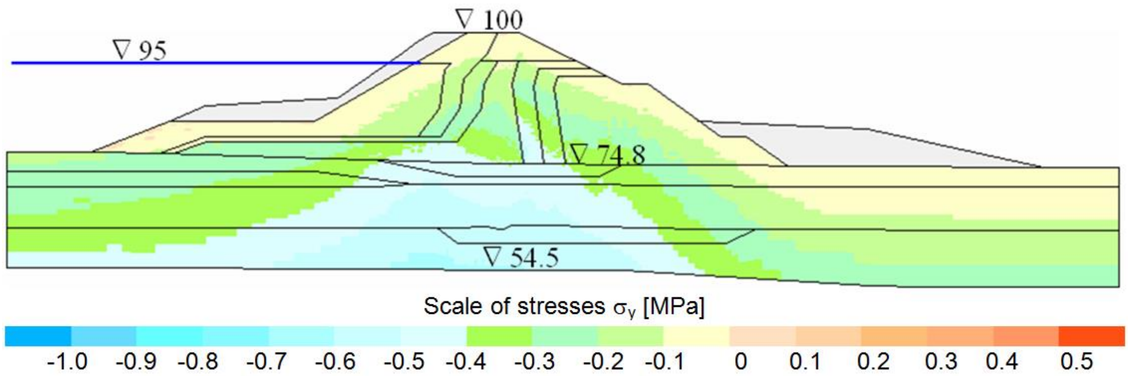

Figure 10. Vertical stresses σ_y in the dam body and foundation for the moment of construction completion and reservoir filling

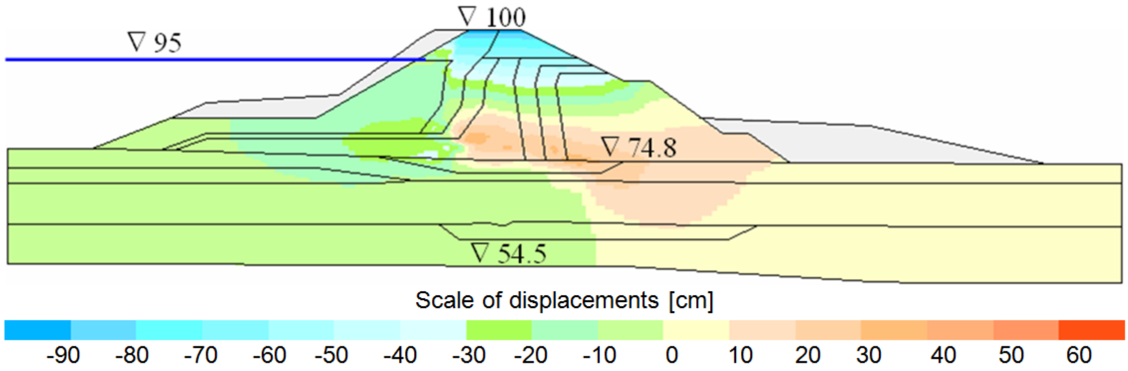

Figure 11. Structure displacements at failure development

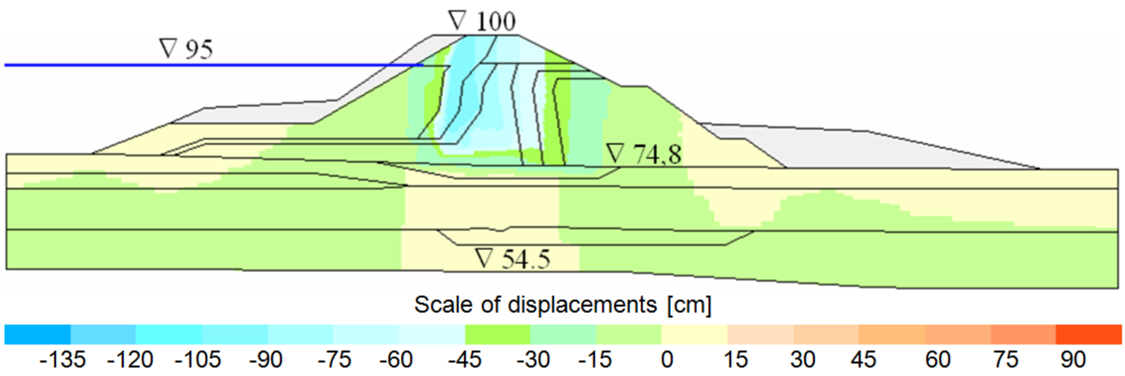

Figure 12. Vertical structure displacements at failure development

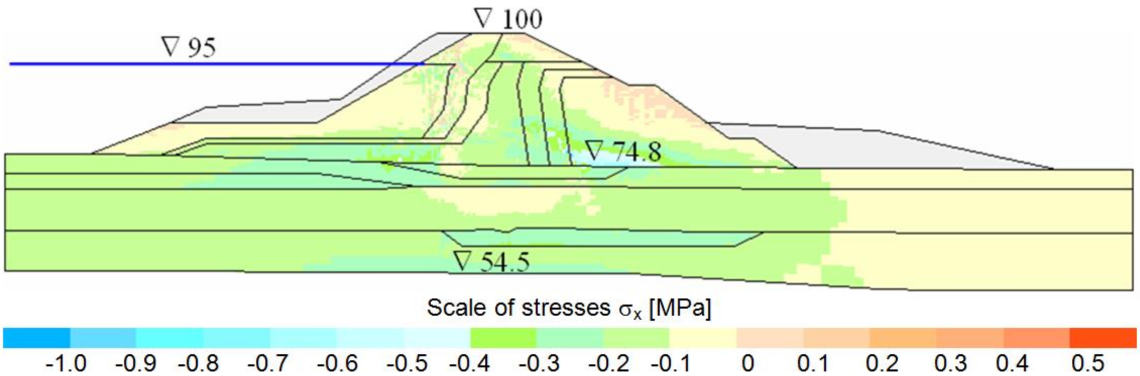

Figure 13. Horizontal stresses σ_y in the dam body and foundation at the end of failure

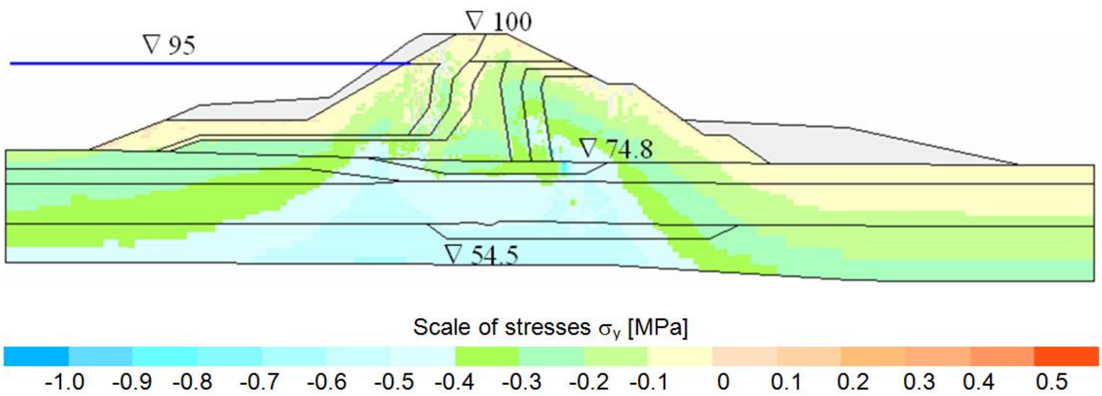

Figure 14. Vertical stresses σ_y in the dam body and foundation at the end of failure

Loss by the dam central part of its load bearing capacity resulted in redistribution of stresses in the dam (Figs. 13, 14). The shells took larger vertical loads; stresses σ_y in them increased sharply (Fig. 14). Vice versa, stresses σ_y in the foundation under the core considerably decreased.

The level of compression in the downstream shell sharply increased also by stresses σ_x (Fig. 13). The maximum value of stresses σ_x amounted to 0.9 MPa. This is connected with transfer of the core lower part loads to it. By the results of computations, in the upper part of the downstream shell the vertical spalled joints appeared, which corresponds to the field data [14].

At arrangement of the seepage-control wall the structure SSS slightly changed. Increments in displacements and stresses in the dam body turned to be small. This is connected with the fact that the wall accumulated only those horizontal loads which the dam had already taken earlier.

The wall displacement curves are shown in Figures 15, 16. The wall displacement curve has an irregular shape. Its maximum is in the core lower part, weakened by scour, i.e. approximately in the middle of the wall height. The clay-cement concrete wall maximum displacement amounted to 10.1 cm. The wall top and bottom have less displacement: not exceeding 7 cm.

At constructing the reinforced concrete wall the wall displacements become more smooth (Fig. 16), but generally the wall follows soil deformations. The reinforced concrete wall maximum displacement amounted to 7.9 cm.

The shape of displacement curve evidences about the wall complicated bending deformations. Apart from the main bend in maximum displacements the curve also has local bends in the zones of contact with soils of various properties. In the zone of maximum displacement the wall bend toward the downstream side.

The wall bend results in irregular distribution of vertical stresses σ_y in it. The most dangerous part of the wall is in the zone of maximum bends. In this part the compression level on the upstream face increases, on the downstream face it decreases. There are two more such sections. All these sections are confined to failure zones in the core and in the foundation. At the section between the failure zones the bend tends to the upstream side, therefore, compression occurs on the upstream face.

When the wall is made of clay-cement concrete the impact of bend deformations on values of stresses σ_y is weak (Fig. 15): no tensile stresses in the wall occur.

In the wall made of reinforced concrete the characteristic feature is appearance of considerable tensile stresses (Fig. 16). They are many times more than concrete tensile strength. That is why it is desirable to use the material with low deformation modulus in order to avoid cracking in the wall.

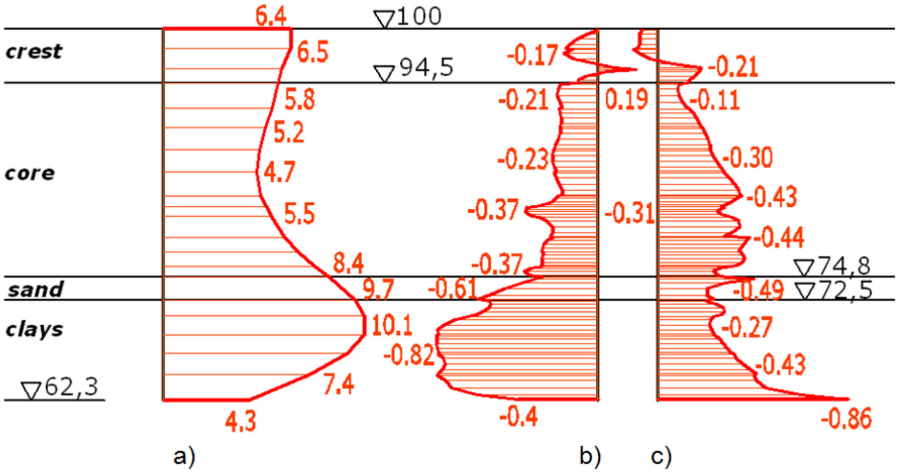

Figure 15. Stress-strain state of clay-cement concrete wall:
a – horizontal displacements from seepage forces; b – vertical stresses σy on the upstream face; c – vertical stresses σy on the downstream face

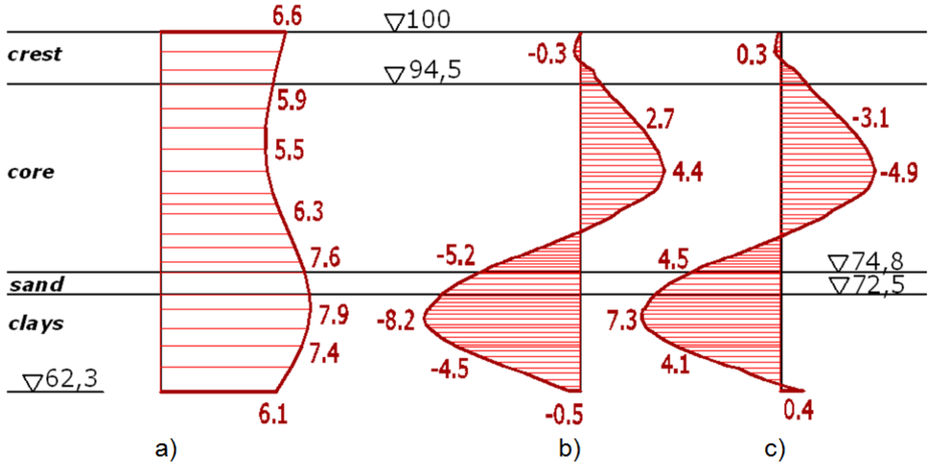

Figure 16. Stress-strain state of concrete wall:
a – horizontal displacements from seepage forces; b – vertical stresses σ_y on the upstream face; c – vertical stresses σ_y on the downstream face

The greatest compressive stresses σ_y appear on the wall foot (Fig.15). These stresses are less than clay-cement concrete compressive strength, which amounts to 1-2 MPa [18,19]. There is no danger of compressive strength failure.

Conclusions

1. The problem of stress-strain state of the wall constructed as a new seepage-control element of failed earhfill dam has a number of peculiarities which complicates its solution. The result of solution to a great extent depends on consideration of these peculiarities, adequacy of the structure design scheme. At computations it is necessary to take into account:

   – Dam SSS peculiar features before construction of the wall in it,
   – Process diagram of the wall construction by method of the «cutoff wall»,
   – Variation of loads on the structure from seepage flow,
   – Presence of failure zones and soil subsidence in the dam,
   – Elastic–plastic character of soils deformation.

2. Solving the problem of the seepage-control wall SSS in a failed eathfill dam requires solving the seepage problem for determining seepage loads on the structure. Due to the fact that construction of the wall with separate bored piles is a rather durable process, seepage load on the wall forms durable time. It may be also assumed that the wall will perceive seepage forces when clay-cement concrete is already hardened.
3. The peculiar feature of seepage-control wall operation on failed eartfill dam is the fact that earlier the dam had already perceived horizontal loads and was adapted to their perception. Therefore, horizontal wall displacements due to seepage load are not large. This is favorable for safety of the wall as a seepage-control element.
4. The main unfavorable factor complicating operation conditions of the seepage-control wall in the failed dam is the fact that the soil mass surrounding it has heterogeneous structure and may contain soil zones with disturbed structure and low strength. Therefore, at perceiving horizontal forces the dam is subject to complicated bending deformations which may worsen its tensile or compressive strength.
5. For material of the seepage-control wall in the failed dam it is recommended to use plastic clay-cement concrete, which by deformability is close to the surrounding soil mass with secant modulus of deformation not exceeding 300 MPa. This permits avoiding appearance of tensile stresses in the wall. Compressive stresses in the wall will not exceed the clay-cement concrete compressive strength.
6. At solving the considered problem we worked out and used the method accounting at structures SSS calculations of subsidence of soils subject to scour by seepage flow.

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Саинов М.П., Анисимов О.В. Напряженно-деформированное состояние противофильтрационной стены, выполненной для ремонта каменно-земляной плотины // Инженерно-строительный журнал. 2016. № 8(68). С. 3–17.

doi: 10.5862/MCE.68.2

Geothermal heat pump in the passive house concept

Геотермальный тепловой насос в концепции пассивного дома

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Key words: energy efficiency; buildings; construction; energy saving; passive house; alternative energy source; geothermal energy; heat pumps; feasibility study

Ключевые слова: энергоэффективность; здания; сооружения; энергосбережение; пассивный дом; альтернативный источник энергии; геотермальная энергия; тепловой насос; технико-экономическое обоснование

Abstract. An actual problem is reducing the cost of engineering systems maintenance of buildings and constructions. These costs include transportation of energy resources from source to consumer, complexity of the heating systems, caused by a large amount of equipment, and as a consequence, the presence of excessive heat losses. One solution is construction of buildings that meet modern energy efficiency requirements.

A set of parameters that contribute to the implementation of the "Passive House" concept was considered, including the use of geothermal heat pumps for the heating system as an alternative production of thermal energy. The main characteristics of the heat pump were established. It was revealed that the cost of heating and air conditioning will not exceed the maximum. The economic efficiency of the chosen technical solution was considered. This research has the prospect of further development.

Аннотация. Актуальной проблемой является снижение затрат на обслуживание инженерных систем зданий и сооружений. К таким затратам относят транспортировку энергоресурсов от источника к потребителю, сложность систем теплоснабжения, обусловленная большим количеством оборудования, и как следствие, наличие излишних тепловых потерь. Одним из решений является строительство зданий, соответствующих современным требованиям энергоэффективности.

Был рассмотрен комплекс параметров, которые способствуют реализации концепции «Пассивный дом». В том числе применение геотермальных тепловых насосов в качестве альтернативного производства тепловой энергии для системы теплоснабжения. Установлены основные характеристики для теплового насоса. Выявлено, что затраты на отопление и кондиционирование не будут превышать установленный максимум. Рассмотрена экономическая эффективность выбранного технического решения. Данное исследование имеет перспективу дальнейшего развития.

Introduction

Implementation of energy efficiency measures can significantly reduce the amount of energy consumption and the cost of payment for utility services. Energy saving effect is achieved through the sum of architectural, construction and engineering solutions aimed at energy savings [1–6].

At the stage of architectural, constructive and engineering design energy efficiency is achieved by:

Kostenko V.A., Gafiyatullina N.M., Semchuk A.A., Kukolev M.I. Geothermal heat pump in the passive house concept. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 18–25. doi: 10.5862/MCE.68.2

- reduction of the outer shell specific area per unit volume is achieved by the most compact space layout;
- targeted selection of the object shape and orientation in view of the energy field properties of renewable sources;
- increase of external cladding thermal properties through the use of efficient thermal insulation materials;
- capacity control of combined extract-and-input systems in accordance with the required air exchange in the attended rooms and as a consequence avoiding of heat overspending in ventilation systems heaters;
- installation of the system of automatic electronic control of the internal building temperature;
- the use of alternative sources of energy for building heat supply.

An indicator of energy efficiency of the object is the number of heat energy consumption per square meter (kW·h/m²) during the year or the heating season [3, 11, 12]. On average, it amounts to 70–140 kW·h/m² for buildings constructed after 2015 [7]. Passive House is a building, where this indicator does not exceed 15 kW·h/m² [8, 9]. This criterion is achieved through intelligent design and implementation of the 5 Passive House principles: proper shape of the building, thermal bridge free design, good insulation of the building outer shell, combined extract-and-input ventilation system with heat recovery, alternative energy sources. Buildings complying with the Passive House standard [8] are rapidly spreading across Germany, Austria and Switzerland. In Germany, the current growth rate of buildings complying with the Passive House standard amounts to 100 %, and in January 2004, more than 4000 dwelling units (equivalent to about 100 m² each) had been built.

To significantly reduce the ever-increasing demand for energy, it is necessary to use different approaches that limit its consumption. It is necessary to reduce heat losses, as well as to organize a more economical method of producing energy, for example, from renewable energy sources. Only a combination of several solutions can give a rational economy.

The aim of this study is to determine the possibility of applying heat pumps in the design of Passive House in the given climatic and geographical conditions.

To achieve this goal, it is necessary to solve the following objectives:

1. Determine the optimal location in the space of a given geographical position.
2. Develop architectural planning and design solutions.
3. Propose technical solutions to reduce energy consumption.
4. Perform a feasibility study of the selected technical solutions.

Methods

The object of the research is a two-story 7-apartment townhouse for year-round use. The projected building is located in the Vyborg district of the Leningrad region, on the shore of Glubokoye Lake. The terrain of the area is particularly distinguished by the presence of hilly and granite rocks in the ground. The advantage of the chosen type of structure is a decrease in the number of external walls and vertical distribution of rooms, thereby area of the roof is reduced.

Calculate the compactness coefficient:

$$K_K = \frac{A_H^{sum}}{V_H}, \tag{1}$$

where A_H^{sum} – sum of the building envelope areas, m²;

V_H – heated volume of the building, m³.

In this case, the compactness coefficient is 0.61, which corresponds to the norm for the two-storey slab blocks [10].

Orientation of the glazed facade is directed to the southwest party that will favorably influence natural lighting and inflow of heat from solar radiation [3, 4].

As in most European countries with high requirements to the level of thermal protection of building envelopes, it is planned to apply frame technology in the projected building. To meet requirements imposed on Passive House it is necessary to choose the optimum thickness of insulation. Through the use of the most effective insulation thickness of the walls of frame buildings is the lowest in comparison with similar (wood and stone) [11]. In this case to use the product from innovative heat-insulating material is offered – cellulose wool, the thermal conductivity is equal to 0.04 W/m·K.

Installation of an Air Handling Unit with recuperation will help to achieve comfortable microclimate. This system purifies and humidifies air, which is essential in the city conditions [8, 18].

For Heat Losses calculation through enclosure it's very convenient to use the value inverse to the reduced total thermal resistance, which in International Standards is called heat-transfer coefficient or U-value.

It is convenience is encompassed in its dimension: W/m²·ºC.

The value given shows which amount of heat energy goes through enclosure with the area 1 m² under the internal and external temperature difference of 1 ºC from both the sides of enclosure. For heat calculation amount (kW·h) going through 1 m² of an external wall, U-value must be multiplied by the amount of heating period hours and middle temperature difference of a heating period. This data is defined for every climatic region in standard [12]. Finally, we get summary heat energy losses through 1 m² of exterior wall with the value of heat-transfer coefficient equal to U = 0.4 W/m²·ºC:

$$Q = \frac{U \cdot (t_{in} - t_h) \cdot z_h \cdot 24}{1000}, \qquad (2)$$

where t_{in} – inner temperature of air in a room, taken according to standard [13] equal to 20 ºC;

t_h – middle temperature of outer air for a heating period, taken for climate conditions of the Leningrad Region according to standard [12] equal to minus 2.9 ºC;

z_h – the amount of days in a heating period, taken for Civil Engineering, located on the territory of the Leningrad Region – 228 days;

24 – the number of hours in a day;

1000 – conversion coefficient of heat transfer capacity (from W into kW).

Thus, using the formula (2) we can calculate average heat losses for a heating period for 1 m², in kW·h.

Let's note that the relation $(t_{in} - t_h) \cdot z_h$ in the formula (2) means heating degree days (GSOP) [14]. For residential building, located on the territory of the Leningrad Region GSOP = 5221 ºC days. Thus, formula (2) will take a more shortened form:

$$Q = 0.024 \cdot U \cdot GSOP \qquad (3)$$

Thus, we have defined the amount of heat losses Q = 50.1 kW·h/m² = 43.1 Mcal/m², which corresponds to a normal level of unit heat energy consumption on heating and ventilation systems of 2–3 storey connected buildings constructed after 2015 for a heating period, $q_{o,year}$ = 75 Mcal/m².

Knowing useful floor area, we can calculate heat consumption of a building during a year: Q = 50123.5 kW·h = 43098.5 Mcal.

According to the II law of thermostatics, transmition of heat capacity in a pump is offset by the work of compressor (Michaelson scheme). For the work of heat pump having cooling source with the thermostat (with the constant temperature) is essential [16–24].

In rock soils (with the coefficient λ = 1…3 W/(m·K)) where the object of our research is located, the adiabatic conditions are executed and the thermal regulation of layers is held. In other words, for getting necessary heat output in this soil deep drilling is essential that will lead to high expenses.

Taking into account that in 20 meters zone from site development Glubokoe Lake is located, using pump taking heat from the outer water basin of an unlimited volume (such as lake) is more rational (Fig. 1).

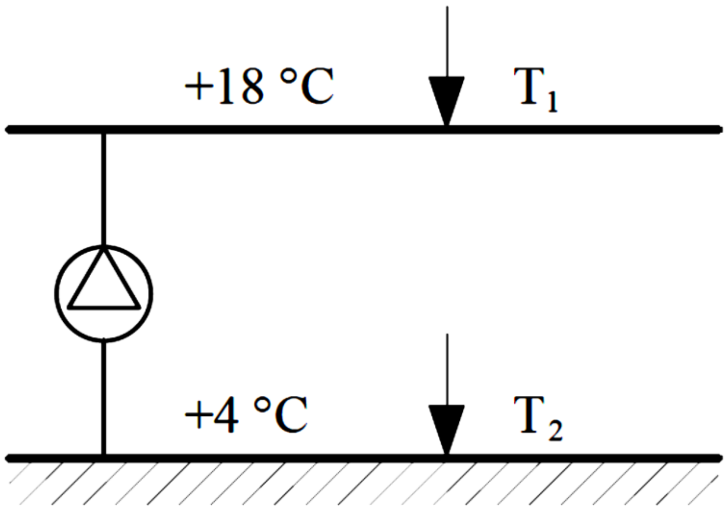

Figure 1. Temperature zones difference

$$\varepsilon = \frac{q_2}{l_n} \longrightarrow \max \qquad (4)$$

The excess of cooling coefficient over 1 shows that by means of relatively high q_2 and low l_n we can get maximum increment of refrigeration efficiency.

It's known that 1 meter of a heat pump tube located on the bottom of a lake gives 50 W of heat energy. Let's calculate the parameters of a heat exchanger with account of 20 meters distance.

Heat transmission equation has the following form:

$$Q = k \cdot \Delta t \cdot A_{TA}, \qquad (5)$$

where k – heat transmission coefficient;

Δt – temperature pressure;

A_{TA} – surface area of a heat exchanger.

Calculations show that the surface of heat exchange, formed by tube sheet with the length of 5…10 m, filled with Freon gas (saturation temperature of which is minus 50°C) might have the outer diameter equal to 8 mm.

Out of economic considerations, there are two regimes of functioning: one is heat source in winter and another one is cold in summer. It is also used for water heating in DHW system [24–28]. So there is an economy in three directions: heat supply, pre-heating and air-cooling of ventilation air-conditioning systems, heating of water for DHW.

Methods of calculating capital costs for additional insulation, operating costs before and after thermal insulation, as well as the payback period of energy-saving measures are described in detail in the works [29–33]. To determine the simple payback, the following basic equation was obtained:

$$T = \frac{\Delta C}{\Delta E}, \qquad (6)$$

where ΔC – capital expenditures, rub.;

ΔE – economic effect achieved as a result of energy saving measures, rub./year:

$$\Delta E = \sum Q \cdot c_т, \qquad (7)$$

where $c_т$ – the rate for the calculation of the amount of payment for utility services with VAT in St. Petersburg for 2016 according to the data of the St. Petersburg Administration official website [34], rub./Gcal.

Capital costs for the heat pump installation (taking into account the energy consumed by the heat pump) amount to 4 696 380 rub.

The economic effect amount to 126 663 rub. per year.

Heat tariffs increase annually. This means that the annual cost savings will increase with each subsequent year (heating period).

Taking into account the above-mentioned factors, the projected payback period of investment in additional facades insulation is determined by a logarithmic equation [19–24]:

$$T = \frac{ln\left[1+\frac{\Delta C}{\Delta E}\cdot\frac{(r-i)}{(1+i)}\right]}{ln\left[\frac{1+r}{1+i}\right]}, \quad (8)$$

where r – coefficient characterizing the average annual growth of thermal energy tariffs;

i – coefficient of future cash flows discounted at the key rate of the Central Bank of the Russian Federation.

Equation (8) allows to calculate the payback period (T) of energy-saving measures, taking into account the total capital expenditure for its implementation (ΔC), the rising cost of tariffs for thermal energy (r), discounting future cash flows (i), achieved by cost-cutting as a result of the implementation of energy-saving measures.

It should be noted that several time-dependent parameters includes in the equation (8): the dynamics of tariff raising for thermal energy (r) and interest rate (i), by which discounted future cash flows is estimated, accumulated as a result of the introduction of energy-saving measures. At the present time it is impossible to clearly know how these variable parameters will change over time in the future. Therefore, to solve the problem of estimating the projected payback period of investment in energy efficiency magnitude r was adopted of the average over the last 5 years – 16 %, and the value i – as of 2016 – 11 %.

In this case the payback period of investment will amount to 23 years.

Results and Discussion

The result of the research is the Passive House project. The following architectural, construction and engineering solutions aimed at energy savings were given:

- vertical distribution of internal rooms and reduction of the roof area. Compactness coefficient is 0.61;
- orientation of the glazed facade to the southwest, in accordance with the solar insolation;
- application of innovative thermal insulation material Cellulose Fibre as insulation of the building envelope;
- installation of the combined extract-and-input system with heat recovery;
- installation of the geothermal heat pump with two modes of operation: the source of cold in the winter and heat in the summer.

Energy-saving effect can be achieved only when all of these technical solutions are used together.

Numerous studies [1–11, 16–33] carried out in different countries of the world showed the prospect of development in the energy efficiency industry. Broad experience was gained in performing parametric evaluations and successfully developing appropriate passive solutions for different climates. The leading authority in the field is the Darmstadt Passivhaus Institut founded in 1996 as an independent research institution employing physicists, mathematicians and civil, mechanical and environmental engineers. Another important research center is at Fraunhofer Institute for Solar Energy in Freiburg.

Conclusions

In this paper, we give details about a project devoted to investigate in what extend renewable energy is useful for energy supply (i.e. heating, cooling and domestic hot water) in terms of technical feasibility and in terms of thermal comfort of passive houses.

A two-story 7-apartment townhouse was accepted for Passive House project. A simple ideal model is adopted for the subsoil heat exchanger. Based on the foregoing, it can be argued that the aim to determine the possibility of using geothermal heat pump in the Passive House has been achieved. Our results show that Pirmasens Passive House heating is necessary during November–March, with January requiring the highest level of heating. The yearly relative total thermal load is 10.2 kWh/m^2, which is below the limit of 15 kWh/m^2 allowed by passive house requirements. The conducted feasibility study showed that the payback period is less than 23 years old.

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doi: 10.5862/MCE.68.3

Moisture sorption models for wood

Модели сорбционной влажности древесины

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Key words: moisture of wood; sorption isotherm; mathematics model; temperature dependent models; numerical calculations of wooden structures

Ключевые слова: влажность древесины; изотермы сорбции; математическая модель; модели зависимости температуры; числовые расчеты деревянных конструкций

Abstract. While making calculations for non-steady heat-and-moisture exchange processes in building envelope constructions it is necessary to consider moisture sorption isotherms of the materials in use. Fifteen aqueous vapor sorption models have been analyzed in order to select the simplest one that represents conventional equilibrium wood moisture values in the most accurate way. Hailwood-Horrobin and Peleg modified equations with three and four empirical constants respectively are the most suitable ones for description. When selecting models for calculations in a climatically defined range of air temperature and relative humidity values, these equations might be in preference to others. The dependence of the constants in these equations on the ambient air temperature have been calculated.

Аннотация. При расчетах нестационарных процессов тепловлагопереноса в ограждающих конструкциях зданий необходимо знание изотерм сорбционной влажности материалов. Пятнадцать моделей сорбции паров воды проанализированы с позиции выбора наиболее простой и точно описывающей принятые в инженерной практике значения равновесной влажности древесины. Перспективными для описания изотерм сорбции при различных температурах являются модифицированные уравнения Hailwood-Horrobin с тремя и Peleg с четырьмя эмпирическими константами. При выборе моделей для численных расчетов эти уравнения могут иметь приоритетное значение в диапазоне природно-климатических температурно-влажностных вариаций наружного воздуха. Рассчитаны зависимости констант этих уравнений от температуры окружающего воздуха.

Introduction

The way moisture affects construction materials is thoroughly studied. In most dense construction materials, e.g. cement concrete and mortar, high moisture content at positive temperatures leads to cement hydration, which results in increased hardness and density of the material due to pore colmatation with hydration products and surface carbonation.

In highly porous thermal insulation materials high moisture content increases thermal conductivity, which leads to increased heat loss through building envelope constructions.

In case the thermal conductivity factor that depends on moisture sorption of materials and corresponds with usage conditions A or B according to Construction Regulations SP 50.13330.2012 “Thermal protection of buildings. Updated edition. Construction Norms and Regulations SNiP 23-02-2003” is used in thermotechnical calculations, construction materials are often overused. Calculation results with regard to material moisture content depending on air temperature and relative humidity in the climatic conditions of Krasnodar, Russia, published in Paper [1] showcase that the reduced total thermal resistance value exceeds the normatively calculated value by 26, 15 and 16 percent for single-layer walls built of foamed concrete, keramzit concrete and keramzit-perlite concrete respectively. When a triple-layer wall panel was calculated for Moscow climatic conditions, this value was overstated by 29 %.

The author states that a higher accuracy of calculations and a lower consumption of construction materials can be achieved by taking into account the dependence of moisture sorption and thermal conductivity of construction materials on temperature when calculating heat and mass transfer values through building envelope constructions and their reduced total thermal resistance.

The article [2] presents the results of comparison between the working moisture content of various construction material samples and the moisture sorption of the same samples at 80 and 97 % relative air humidity. For instance, the working moisture content of a foamed polystyrene sample taken from a construction in Novosibirsk, Russia (usage conditions A) appeared to be almost 60 times higher than the moisture sorption (80 %). For a brick sample from Moscow it was 4 and 10 times higher. The article states that the thermotechnical characteristics of various materials determined by existing construction rules and regulations are outdated. Moreover, there are no such values determined for newer types of materials. The authors of the article suggest that the working moisture content of construction materials be calculated using a non-steady method according to Russian State Standard GOST 32494-2013 "Buildings and Constructions. Mathematical modeling of heat-and-moisture processes for building envelope constructions" with further data correction according to the results of field tests. The accuracy of such method is proved in Paper [3]. The above paper compares the results of calculations with the results of field tests determining working moisture content of mineral wool and foamed polystyrene in Saint-Petersburg, Russia and Novosibirsk. The difference between calculations and test results does not exceed 15%.

Nowadays, wooden house-building is rapidly gaining popularity in European countries. The increased use of wooden constructions made of materials from renewable sources benefits sustainable development. Wooden buildings are in great request because they are built of materials from renewable sources and hence are environmentally friendly. Wooden multi-story buildings are successfully built and used abroad [4].

According to the standard STO 00044807-001-2006 "Heat-protective characteristics of building envelope constructions" developed by the Russian Construction Engineering Association (ROIS), the estimated physical decay period of wooden buildings is 90 years.

Unlike most constriction materials, wood is known for its increased moisture sorption and decay tendency. Moreover, wood is an anisotropic material, which means its thermal conductivity and vapor permeability along the grain are respectively 2 and 5 times higher than across the grain. Thus, it is extremely important to consider the moisture sorption and thermal conductivity dependence on temperature when making calculations for heat and mass transfer processes through building envelope constructions and also to calculate the working sorption content for wooden constructions.

For porous materials the equilibrium moisture content depends on air temperature and humidity. The purpose of this work is to select a simple yet accurate mathematical model describing the published results of equilibrium moisture content and thermal conductivity experiments with wooden and composite constructions for numerical modeling in the range of air temperature and humidity values typical for a certain climate. This work is not aimed at studying physicochemical processes caused by vapor sorption and desorption. Physico-chemical aspects of wood adsorption along with existing theories on the subject were thoroughly studied in papers [5], [6] by B.S. Chudinov, E.A. Kolosovskaya and S.R. Loskutov.

Methods

According to the classification suggested in Paper [7], there are five types of sorption isotherms.

The International Union of Pure and Applied Chemistry (IUPAC) distinguishes between six types of adsorption [8] illustrated in Figure 1.

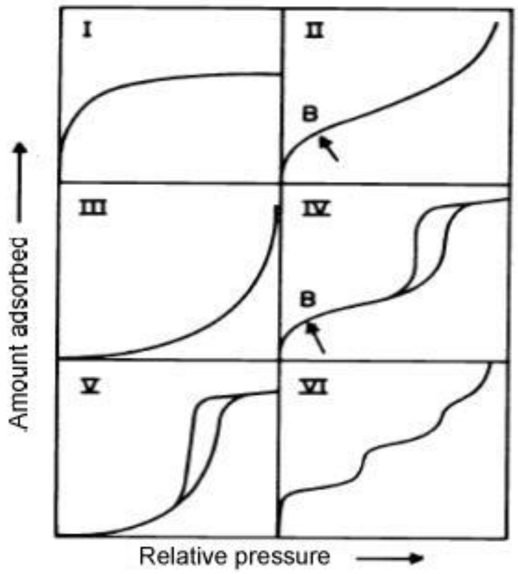

Figure 1. Isotherm types [8]

Isotherm I illustrates monolayer adsorption typical of materials with well-developed inner structures and relatively small surface areas, such as activated charcoal, zeolites and molecular sieves. In this case the limits of adsorption are defined by the micropore volume.

Isotherm II illustrates multilayer monomolecular adsorption in non-porous or coarse-porous adsorbents in conditions of strong interaction between the adsorbate and the adsorbent with a distinguished bending point. It is assumed that this point is where the formation of the monolayer finishes and next layers of the adsorbate start forming.

Isotherm III illustrates adsorption in non-porous or coarse-porous adsorbents in conditions of weak interaction between the adsorbate and the adsorbent. This isotherm is bent towards the partial pressure axis and does not have a distinguished or indistinct bending point.

Isotherm IV characterizes adsorption in conditions of strong interaction between the adsorbate and the adsorbent (type II) when the hysteresis effect takes place. In contrast to the type II, the limit mesopore capillary condensation in the higher range of partial pressure values of the adsorbed gas is distinguished in this case. This isotherm illustrates the adsorption in a hydrophilic material that is swelling to the limit state [9]. This is a typical case for industrial adsorbents.

Isotherm V illustrates adsorption with the hysteresis effect in conditions of weak interaction between the adsorbate and the adsorbent when the limit mesopore capillary condensation in the higher range of partial pressure values of the adsorbed gas is distinguished. Such isotherms are typical for aqueous vapor adsorption by coal.

Isotherm VI characterizes stepwise multilayer adsorption, in which case the height of steps depends on the temperature and the adsorbate-adsorbent system.

Water sorption in most construction materials, including wood, is characterized by Isotherm II (Fig. 2).

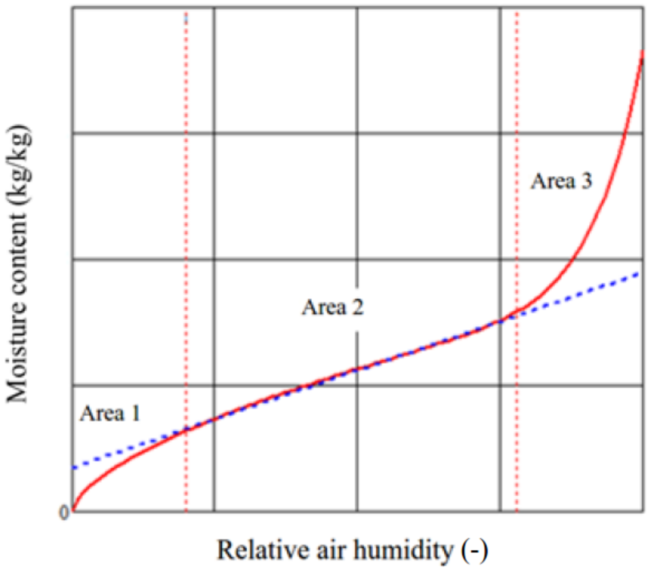

Figure 2. Sorption in wood. Isotherm diagram with areas marked

In Paper [10] the physical sorption mechanism is described in the following way. There are three areas distinguished on the sorption curve. Area 1 of the sorption isotherm illustrates the way the Van der Waals force affects water molecules. Water molecules adsorption continues until the monolayer covering the external cell wall surface forms. At this moment, the water stays in the solid state due to chemical bonds. This area flows to Area 2 when the first layer becomes saturated. At this stage the water molecules adsorption in the first layer takes place which creates the second layer. In this area the isotherm is linear. In Area 3 there might be liquid water in wood capillaries. Supposing that the adsorbed water covers the cell walls evenly in the transition zone between Areas 2 and 3, the thickness of the layer becomes sufficient for liquid water generation in the pores as the result of capillary condensation. Thus, the microcapillary water forms a continuous phase.

Sorption isotherm equations. Langmuir adsorption isotherm equation (1) assumes that the aqueous vapor condensates as a monolayer and is basic for models considering the adsorption of two or more layers (BET, GAB, H-H, Dent models).

$$w = \frac{c \cdot \varphi \cdot w_0}{c \cdot \varphi + 1} \quad (1)$$

BET equation was first suggested by Brunauer, Emmet and Teller [11].

$$w = \frac{w_0 \cdot c \cdot \varphi}{(1 - \varphi) \cdot (1 + (c - 1) \cdot \varphi)} \quad (2)$$

BET (2) is the most commonly used equation and is fundamental for multilayer sorption isotherms interpretation. In this equation, w is the equilibrium moisture content of the material (kg/kg of dry material); w_0 is water content in the monolayer adsorbed by dry adsorbent (kg of water/kg of dry substance); φ stands for relative air humidity (water activity), c is the adsorption heat constant related to the sorption heat difference between the first and the following layers.

BET equation is used in the 0.05–0.45 air humidity range. BET equation is used for surface area definition. In general, with an arbitrary number of layers (n) the BET theory leads to the following equation [9], [10]:

$$w = \frac{w_0 \cdot c \cdot \varphi}{1 - \varphi} \cdot \frac{(1 - (n + 1) \cdot \varphi^n + n \cdot \varphi^{n+1})}{(1 + (c - 1) \cdot \varphi - c \cdot \varphi^{n+1})} \quad (3)$$

In the monolayer case (n=1), equation (3) transforms into the Langmuire equation (1).

Hailwood-Horrobin model (H-H) [12]:

$$w = \frac{1800}{M_P} \cdot \left[\frac{K \cdot \varphi}{1 - K \cdot \varphi} + \frac{\sum_{i=1}^{n} i \cdot (K \cdot \varphi)^i \cdot K_1 \cdot K_2 \ldots K_i}{1 + \sum_{i=1}^{n} (K \cdot \varphi)^i \cdot K_1 \cdot K_2 \ldots K_i}\right] \quad (4)$$

For a monomolecular adsorbed water layer this is written in Paper [13] as:

$$\mathrm{w} = \frac{1800}{\mathrm{M_P}} \cdot \left[\frac{\mathrm{K_2 \cdot \varphi}}{1 - \mathrm{K_2 \cdot \varphi}} + \frac{\mathrm{K_1 \cdot K_2 \cdot \varphi}}{1 + \mathrm{K_1 \cdot K_2 \cdot \varphi}}\right] \quad (5)$$

For two monomolecular layers (n=2) this is written in Paper [14] as:

$$\mathrm{w} = \frac{1800}{\mathrm{M_P}} \cdot \left[\frac{\mathrm{K \cdot \varphi}}{1 - \mathrm{K \cdot \varphi}} + \frac{\mathrm{K_1 \cdot K \cdot \varphi + 2 \cdot K_1 \cdot K_2 \cdot K^2 \cdot \varphi^2}}{1 + \mathrm{K_1 \cdot K \cdot \varphi + K_1 \cdot K_2 \cdot K^2 \cdot \varphi^2}}\right] \quad (6)$$

The effect of temperature on w is taken into account by the functionality of each equation member described by quadric polynomials:

$$\mathrm{M_P} = 349 + 1.29 \cdot \mathrm{T} + 0.0135 \cdot \mathrm{T}^2$$

$$\mathrm{K} = 0.805 + 0.000736 \cdot \mathrm{T} - 0.00000273 \cdot \mathrm{T}^2$$

$$\mathrm{K_1} = 6.27 - 0.00938 \cdot \mathrm{T} - 0.000303 \cdot \mathrm{T}^2$$

$$\mathrm{K_2} = 1.91 + 0.0407 \cdot \mathrm{T} - 0.000293 \cdot \mathrm{T}^2$$

In equations (3-6), W stands for material moisture content (%); φ is relative air humidity (%); 1800 is the molecular weight of water multiplied by 100 (gram/mol); $\mathrm{M_P}$ is the molecular weight of the hydrate-forming polymer (gram/mol); n is the number of adsorbed molecular layers; $\mathrm{K_i}$ is the equilibrium constants between free and bound water in the wood; T stands for temperature (°C).

The formulas for K, $\mathrm{K_1}$ и $\mathrm{M_P}$ factors calculation are given in Paper [6], equation (5).

Guggenheim-Anderson-de Boer model (GAB) is the result of BET theory development. It is described as

$$\mathrm{w} = \frac{\omega_0 \cdot \mathrm{K \cdot c \cdot \varphi}}{(1 - \mathrm{K \cdot \varphi}) \cdot (1 - \mathrm{K \cdot \varphi + K \cdot c \cdot \varphi})} \quad (7)$$

Factors c and K are sorption constants related to the interaction energy between the first layer of adsorbed molecules and the following layers in the place of sorption:

$$\mathrm{c} = \mathrm{c_0} \cdot \exp\left[\frac{\mathrm{H_0 - H_n}}{\mathrm{R \cdot T}}\right] \quad (8)$$

$$\mathrm{K} = \mathrm{k_0} \cdot \exp\left[\frac{\mathrm{H_n - H_l}}{\mathrm{R \cdot T}}\right], \quad (9)$$

where $\mathrm{c_0}$, $\mathrm{k_0}$ are entropy accommodation factors; $\mathrm{H_0}, \mathrm{H_n}$ and $\mathrm{H_l}$ stand for the enthalpy of monolayer in the following layers and the liquid respectively. GAB model describes moisture sorption of materials in a wide range of relative air humidity values. Due to K factor in the equation it is possible to describe stages of aqueous vapor adsorption following the monomolecular stage up to the stage of liquid phase formation in the material pores. When K = 1 the equation transforms into BET equation [15].

Dent theory equation [16]:

$$\mathrm{w} = \frac{\mathrm{b_1 \cdot b_i \cdot \varphi^2 \cdot w_0}}{(1 - \mathrm{b_i}) \cdot (1 - \mathrm{b_i}\varphi + \mathrm{b_1} \cdot \varphi)} + \frac{\mathrm{b_1 \cdot w_0 \cdot \varphi}}{1 - \mathrm{b_1 \cdot \varphi \cdot b_i \cdot \varphi}} \quad (10)$$

Models HH and Dent can be reduced to the form (11).

$$\mathrm{w} = \frac{\varphi}{\mathrm{C + B \cdot \varphi + A \cdot \varphi^2}} \quad (11)$$

Factors *C, B* and *A* in Equation (11) are calculated by the following formulas:

$$C = \frac{1}{w_0 \cdot b_1} \quad (12)$$

$$B = \frac{b_1 - 2 \cdot b_i}{w_0 \cdot b_1} \quad (13)$$

$$A = \frac{b_i^2 - b_1 \cdot b_i}{w_0 \cdot b_1} \quad (14)$$

For GAB model (7):

$$C = \frac{1}{c \cdot K \cdot w_0} \tag{16}$$

$$B = \frac{1}{w_0} \cdot \left(1 - \frac{2}{c}\right) \tag{17}$$

$$A = \frac{k}{w_0} \cdot \left(\frac{1}{c} - 1\right) \tag{18}$$

Constants b_1, b_i,*w0, K* and *c* can be calculated by solving the respective sets of equations.

Constants *A, B, C* are calculated by empirical data approximation by means of Equation (11).

Even though the semi-empirical model [17, 18] does not have a fundamental theoretical basis, it describes sorption in the same or even a better way than other models above:

$$w = a \cdot \varphi^b + c \cdot \varphi^d \tag{19}$$

In the formula (19) *a*, *b*<1, *c* и *d*>1 are empirical constants.

In order to calculate the equilibrium moisture content of wood the following formulas [19] are used at $\varphi < 0.5$:

$$w = a \cdot \left[b - \left(\frac{T}{100}\right)^2\right] + c \cdot \varphi \cdot \left[d - \left(\frac{T}{100}\right)^2\right] \tag{20}$$

At $0.5 < \varphi < 1$:

$$w = \frac{a}{b - \varphi} \cdot \left[c - \left(\frac{T}{100}\right)^2\right] \tag{21}$$

Factors *a, b* и *c* in formulas (19) and (20) have different numerical values.

Construction materials laboratory of Danish Technology University has published a list of moisture sorption values for a wide range of materials (including different species of wood and other construction materials), where the processes of adsorption and desorption are approximated by one equation [20] with different values of empirical constants *n, A* and w_m for forward and the backward process:

$$w = w_m \cdot \exp\left[\left(-\frac{1}{n}\right) \cdot \ln\left(-\frac{\ln(\varphi)}{A}\right)\right] \tag{22}$$

where w_m stands for the maximum moisture content value.

The crucial meaning of moisture sorption for construction engineering is pointed out in dissertation works by V.G. Gagarin [21] and I.Y. Kiselyov [22]. In Paper [1] the moisture sorption capacity is calculated of construction materials is calculated by the following formula:

$$w(\varphi, T) = (a_m \cdot T + b_m) \cdot \left[\frac{a_a \cdot \exp(b_a \cdot T)}{R \cdot T(-\ln(\varphi))}\right]^{a_r \cdot \exp(b_r \cdot T)} \tag{23}$$

where w is moisture sorption capacity (kg/kg); φ is relative air humidity (Pa/Pa); T stands for temperature (K); a_a, a_m, a_r, b_a, b_m, b_r are empirical constants.

The numerical values of empirical constants for some constructions materials are given in this paper.

For calculations with a fewer number of empirical factors the formula (22) can be presented in a more compact form without the first multiplier:

$$w = \frac{\varphi \cdot c \cdot w_0 \cdot \left(-\frac{a}{R \cdot T \cdot \ln(\varphi)}\right)^{\frac{1}{q}}}{\varphi \cdot c - \varphi + 1} \tag{24}$$

or:

$$w = \frac{\varphi \cdot c \cdot \left(-\frac{a}{\ln(\varphi)}\right)^{\frac{1}{q}}}{\varphi \cdot c - \varphi + 1} \tag{25}$$

Oswin empirical model [23]:

$$w = A \cdot \left[\frac{\varphi}{1-\varphi}\right]^{B} \tag{26}$$

With regard to ambient air temperature:

$$w \ = (b_m + a_m \cdot T) \cdot \left[\frac{\varphi}{1-\varphi}\right]^{\frac{1}{q}} \tag{27}$$

This is used at $\varphi < 0{,}5$.

Approximation quality evaluation method

In order to evaluate the approximation quality of equilibrium water content value *w* depending on relative air humidity φ, the following determination coefficient value was used:

$$R^2 = \frac{\sum_{i=1}^{n}(\check{Y}_i - \bar{Y}_i)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y}_i)^2} \tag{28}$$

where Y_i is the equilibrium moisture content of wood at different temperature and relative air humidity levels (Table 1).$\bar{Y}_i$ is the average equilibrium moisture content; $\check{Y}_i$ stands for the values calculated by the above mathematical modeling formulas. The closer to 1 R^2 is, the higher the quality of a certain model is rated. Y_i values at different temperatures are listed in the Table 1 (taken from Paper [14]).

Table 1. Equilibrium moisture content of wood [14]

Relative air humidity, φ	**Moisture content of wood, w (kg/kg) at the following temperatures**		
	-1.1 °C	**21.1 °C**	**43.3 °C**
0.05	0.014	0.013	0.011
0.1	0.026	0.026	0.022
0.15	0.037	0.035	0.032
0.2	0.046	0.045	0.04
0.25	0.055	0.054	0.049
0.3	0.063	0.062	0.056
0.35	0.071	0.069	0.063
0.4	0.079	0.077	0.07
0.45	0.087	0.085	0.077
0.5	0.095	0.092	0.084
0.55	0.104	0.101	0.092
0.6	0.113	0.11	0.1
0.65	0.124	0.12	0.11
0.7	0.135	0.131	0.12
0.75	0.149	0.144	0.132
0.8	0.165	0.16	0.146
0.85	0.185	0.179	0.166
0.9	0.21	0.205	0.191
0.95	0.243	0.239	0.224

Results and Discussion

*R*² determination factor values describing data approximation for wood at different temperatures (the data taken from [14]) along with numerical values of the respective empirical factors are listed in the Table 2.

Nazirov R.A., Verkhovets S.V., Inzhutov I.S., Bazhenov R.V., Tarasov I.V. Moisture sorption models for wood. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 26–36. doi: 10.5862/MCE.68.3

Table 2. Results of factors calculations in aqueous vapor adsorption equations for wood

Sorption model	Approximation range	Calculation results at the following temperatures					
		-1.1°C		21.1°C		43.3°C	
		Determina-tion factor R^2	Factors values	Determina-tion factor R^2	Factors values	Determina-tion factor R^2	Factors values
(2)	φ=0.05…0.35	0.9993	w_0=0.062 c=5.65	0.9986	w_0=0.061 c=5.50	0.9985	w_0=0,058 c=4.92
(5)	φ=0.05…0.95	0.9998	W=245.833 K=0.750818 K_1=5.6847	0.9996	W=258.602 K=0.7586 K_1=6.0057	0.9995	W=287.775 K=0.7702 K_1=5.8551
(6)	φ=0.05…0.95	0.99999	W=348.939 K=0.8046 K_1=6.3287 K_2=1.8891	0.99998	W=380.645 K=0.8186 K1=6.1195 K2=2.5410	0.99998	W=430.626 K=0.8318 K_1=5.4087 K_2=3.0489
(7)	φ=0.05…0.95	0.9998	ω_0=0.073 c=6.68 *K*=0.751	0.9996	ω_0=0.0696 c=7.01 *K*=0.759	0.9995	ω_0=0.0625 c=6.855 *K*=0.770
(10)	φ=0.05…0.95	0.9998	w_0=0.07322 b_1=5.019 b_i=0.75018	0.9996	w_0=0.06961 b_1=5.3146 b_i=0.7586	0.9995	w_0=0.02549 b_1=5.2795 b_i=0.770169
(11)	φ=0.05…0.95	0.9998	*C*=2.72 *B*=9.57 *A*=-8.72	0.9996	*C*=2.70 *B*=10.265 *A*=-9.34	0.9995	*C*=3.03 *B*=11.32 *A*=-10.517
(19)	φ=0.05…0.95	0.99996	a=0.163321 b=0.793330 c=0.119675 d=6.489193	0.99994	a=0.160191 b=0.797828 c=0.121444 d=6.988122	0.99993	a=0.148004 b=0.816586 c=0.118465 d=7.26708
(20)	φ=0.05…0.5	0.9975	a=0.020 b=7.851 c=-0.0813 d=5.241	0.9968	a=-0.0202 b=8.229 c=-0.013 d=-4.547	0.9967	a=-0.00056 b=-2.1318 c=-0.06992 d=12.281
(21)	φ=0.5…1.0	0.9994	a=0.051 b=1.254 c=8.088	0.9996	a=0.00145 b=1.246 c=8.679	0.9997	a=-0.1112 b=1.231 c=8.254
(22)	φ=0.05…0.95	0.9975	n=0.824 A=0.491 w_{max}=0.27	0.9970	n=0.864 A=0.444 w_{max}=0.264	0.9967	n=0.884 A=0.403 w_{max}=0.25
(23)	φ=0.2…0.95	0.9721	a_m=0.0141 b_m=-0.5433 a_a=0.019 b_a=0.0122 a_r=0.0187 b_r=0.0112	0.9749	a_m=0.0131 b_m=0.9398 a_a=0.0135 b_a=0.01126 a_r=0.0141 b_r=0.0113	0.9766	a_m=0.0142 b_m=1.16 a_a=0.0129 b_a=0.0101 a_r=0.0154 b_r=0.0104
(24)	φ=0.2…0.95	0.9987	w_0 =0.131 c=2.32 a= 2075,41 1/q=0.229	0.9988	w_0 =0.093 c=2.55 a= 7057,58 1/q=0.243	0.9988	w_0 =0.062 c=2.57 a=23583,6 1/q=0.256
(25)	φ=0.2…0.95	0.9987	c=2.32 a=0.000126 1/q=0.229	0.9988	c=2.55 a=0.000166 1/q=0.243	0.9988	c=2.57 a=0.000172 1/q=0.256
(26)	φ=0.05…0.95	0.9846	A=0.0929 B=0.358	0.9860	A=0.0901 B=0.361	0.9869	A=0.0822 B=0.369
(27)	φ=0.05…0.95	0.9846	a_m=175.83 b_m=-47836 1/q=0.358	0.9860	a_m=-24.247 b_m=-7134.7 1/q=0.357	0.9869	a_m=434 b_m=-13792 1/q=0.333

It is clear from the table that formulas (11) and (19) ensure the most accurate approximation (with the exception of Equation (6) which is the basis for the table in [14] and the Table 1).

As well as in Equation (6), the dependence of equilibrium moisture content on temperature in equations (11) and (19) is taken into account by considering the dependence of equation factors on temperature. For Equation (11):

$$A = -5.59 \cdot 10^{-4} \cdot T^2 - 0.0169 \cdot T - 8.74 \quad (29)$$

$$B = 3.69 \cdot 10^{-4} \cdot T^2 + 0.0239 \cdot T + 9.60 \quad (30)$$

$$C = 3.48 \cdot 10^{-4} \cdot T^2 - 7.77 \cdot 10^{-3} \cdot T + 2.71 \quad (31)$$

For Equation (19):

$$a = -0.923 \cdot 10^{-5} \cdot T^2 + 4.50 \cdot 10^{-5} \cdot T + 0.163 \quad (32)$$

$$b = 1.45 \cdot 10^{-5} \cdot T^2 - 8.72 \cdot 10^{-5} \cdot T + 0.793 \quad (33)$$

$$c = -0.5 \cdot 10^{-5} - 20.0 \cdot 10^{-5} \cdot T + 0.1199 \quad (34)$$

$$d = -22.3 \cdot 10^{-5} \cdot T^2 + 0.0264 \cdot T + 6.52 \quad (35)$$

Figure 3 vividly illustrates the proximity of the calculated data when the dependence of empirical factors on temperature is taken into account.

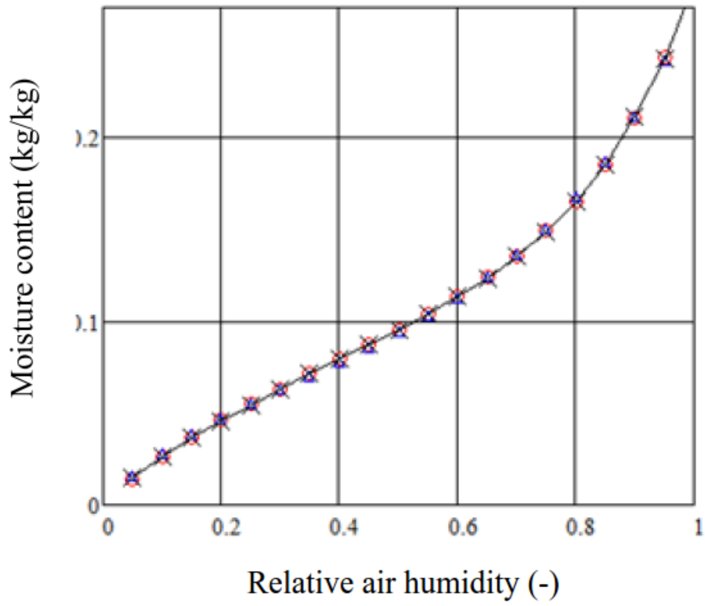

Figure 3. Calculation results comparison at the temperature of -1.1°C

ooo – values published in [14]; ΔΔΔ – values calculated by Equation (11);

×× – values calculated by Equation (19)

Conclusions

A good level of sorption isotherm approximation at a constant temperature can be achieved using equations with three or four empirical constants for selection. The temperature dependence of sorption isotherm on -1.1° C to 43.3° C with minimum possible coefficient of determination of R2 ⩾ 0.9995 can be considered by defining the dependence of empirical constants on temperature. Such accuracy is quite sufficient for the majority of practical engineering calculations. It is important to note that the high accuracy of factors selection for empiric and semi-empiric models in the form of rational function or in the form of the sum of two exponential functions with positive real numbers, such as modified equations of Hailwood-Horrobin (11) and Peleg (19), does not ensure the same accuracy when approximating experimental results for other materials that might not be error-free. However, when selecting models for calculations in a climatically defined range of air temperature and relative humidity values, these functions with minimum amount of empirical constants might be in preference to others.

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Nazirov R.A., Verkhovets S.V., Inzhutov I.S., Bazhenov R.V., Tarasov I.V. Moisture sorption models for wood. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 26–36. doi: 10.5862/MCE.68.3

doi: 10.5862/MCE.68.4

Main inorganic ions and electric conductivity of polluted urban streams

Главные неорганические ионы и электропроводность загрязненных водотоков

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Key words: wastewater; river water; ions; electric conductivity; environmental monitoring; civil engineering

Ключевые слова: сточные воды, речная вода, электропроводность, мониторинг окружающей среды, гражданское строительство

Abstract. Concentrations of main inorganic ions were determined in waters of city streams affected by domestic and industrial wastewaters – the Okhta and the Murinsky creek in St. Petersburg. It was shown that pollution of streams led to increasing of molar fraction for sodium ion and chlorides, decreasing of molar fraction of magnesium, calcium, sulfates and hydrocarbonates. These changes took place while electric conductivity of waters was increasing. Positive correlation coefficients (from 0.35 to 0.63) were found between molar fraction of sodium and parameters connected with wastewater pollutants: total nitrogen (TN), ratio of TN to TOC (total organic carbon), ratio of protein-like fluorescence (excitation at 230 or 270 nm, emission at 350 nm) to humic-like fluorescence (excitation at 230 or 270 nm, emission at 420 nm). The obtained results show that electric conductivity can be applied as an express-method for environmental monitoring in the studied streams. Additional use of ions molar fractions for such purpose is also possible.

Аннотация. Определены концентрации главных неорганических ионов в воде реки Охты и Муринского ручья – водотоков Санкт-Петербурга, загрязненных бытовыми и промышленными сточными водами. Показано, что загрязнение приводит к увеличению мольной доли ионов натрия и хлоридов, снижению мольной доли ионов магния, кальция, сульфатов и гидрокарбонатов, при этом электропроводность воды возрастает. Положительные коэффициенты корреляции (от 0,35 до 0,63) получены между мольной долей натрия и параметрами, связанными с загрязнением сточными водами: концентрацией общего азота (TN), отношением TN к концентрации общего органического углерода, отношением интенсивности флуоресценции белкового типа (длина волны возбуждения 230 или 270 нм, регистрации 350 нм) к интенсивности флуоресценции гуминового типа (длина волны возбуждения 230 или 270 нм, регистрации 420 нм). Полученные результаты показывают, что электропроводность может применяться в качестве экспресс-метода для мониторинга окружающей среды в исследуемых водотоках. Также возможно использование мольных долей ионов в качество дополнительного параметра.

Introduction

Environmental monitoring plays essential role in environmental management and civil engineering. Results of monitoring enhance knowledge of ecosystems and social impacts on them; provide rationale for setting standards and making engineering decisions for protection and rehabilitation of natural systems [1]. Water quality monitoring has a special importance giving information about influence of wastewater effluents on drinking water sources.

Бондаренко Е.А., Ильина Х.В., Андрианова М.Ю., Чусов А.Н. Основные неорганические ионы и электропроводность загрязненных водотоков // Инженерно-строительный журнал. 2016. № 8(68). С. 37–44.

Rivers of big cities usually are affected by untreated domestic and industrial wastewaters that can be discharged on a regular basis or during emergency episodes. Even if amount of direct discharges is gradually decreased due to efforts of municipality and wastewater treatment companies, there is still possibility of pipes misconnection or illicit discharge of wastewaters by individuals or organizations. Such cases took place in St.Petersburg, where in nowadays 98 % of city wastewaters are accepted by canalization and transported to wastewater treatment plants [2]. Significant pollution of rivers in St.Petersburg was sometimes noticed by citizens due to unpleasant smelt, oil sheen, and presence of dead fish. Several such accidents happened in river Okhta [3, 4]. Pollutants in storm waters from industrial and residential areas and filtrates from unauthorized landfills also make worse water quality in rivers of St.Petersburg [5–7].

Rapid detection of pollutants is important in several cases. It helps to find the sources of unwanted substances and prevent inflow of impurities from them in future due to administrative means and engineering measures. For this purpose, express-methods of water quality monitoring are needed. In natural waters with low mineralization measurement of specific electric conductivity (EC) could be a useful express-method of water quality control.

EC has been investigated as marker of contamination from wastewaters discharges [8–12]. It is considered to be useful for screening of the pollution level [9, 11]. For rivers of the North-Western part of Russia natural background concentrations of inorganic salts are small or moderate [13]. This makes possible registration of pollution in rivers by increasing of EC in water samples.

For the Okhta waters cations of calcium and anions of hydrocarbonates are contained in majority [13, 14]. According to the results of monitoring (at observation point Novoye Devyatkino at the boundary of St.Petersburg) sum of concentrations for the dissolved ions in the Okhta waters was in the range from 60 to 140 mg/L [13]. Concentration of ions (as dissolved solids) in untreated domestic wastewaters is usually higher: about 200–1000 mg/L [15, 16]. This data give basis for applying EC as a parameter for water quality monitoring in polluted urban rivers.

Correlations of EC with concentrations of total nitrogen (TN) and fluorimetric parameters that are characteristic of wastewater pollution were found in previous studies [17, 18]. The goal of the actual work was to clarify roles of major inorganic ions in formation of EC in urban river Okhta and its polluted tributary. To achieve the goal the following tasks were set:

– measurement of EC and concentrations of main ions (sodium, potassium, magnesium, calcium, chlorides, sulfates, hydrocarbonates) in waters upstream and downstream outlets of wastewaters;

– revealing connection between ions concentrations and other markers of wastewater pollution, such as TN and fluorimetric parameters of water.

Materials and Methods

Water Samples. Water samples were taken from the Okhta and its tributary the Murinsky creek. The Okhta is considered to be the most polluted river in St.Petersburg. Discharge of wastewater into river Okhta had contributed for about 20 % of its flow rate. The Murinsky creek takes domestic wastewaters from high-rise residential buildings (district Grazhdanka in St. Petersburg); inflow of wastewaters had contributed for about 60 % of its flow rate [19, 20]. Scheme of sampling points location is given in [18].

Series of water samples were collected from July 2013 to March 2014. Three series of samples for each water object were taken, 8–15 samples from the Murinsky creek and 7–17 samples from the Okhta in each series. The samples of each series were collected during the same day and transported to the laboratory. Bottles with water were stored in a fridge at +4...+6°C for several days in vertical position while suspended matter was sedimenting. The upper part of water was analyzed.

Chemical Analysis. EC was measured in the laboratory at the day of sampling by conductometer “HI 8713” (HANNA Instruments) at 20 °C (measurement error ± 5 %). Other parameters were determined in the supernatant after storage of samples. Concentrations of total organic carbon (TOC), inorganic carbon (IC) and TN were determined by analyzer “TOC L vpn-TNM” (Shimadzu, Japan) (measurement error ± 10 %). For the calculations it was supposed that all measured IC was present in the form of hydrocarbonates.

Concentrations of major inorganic cations (potassium, sodium, magnesium, calcium) and anions (chlorides, sulfates) were measured by capillary electrophoresis method on “Capel-103R” (Lumex, Russia) with measurement error ± 15 %.

Bondarenko E.A., Il`ina Kh.V., Andrianova M.Ju., Chusov A.N. Main inorganic ions and electric conductivity of polluted urban streams. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 37–44. doi: 10.5862/MCE.68.4

Fluorescence spectra of water samples were obtained on analyzer “RF 5301 PC” (Shimadzu, Japan) at excitation wavelengths 230 and 270 nm, emission wavelength from 200 to 650 nm. The wavelengths were chosen in the previous investigations [21, 22]. Detailed process of fluorimetric analysis is described in [18]. Ratio of protein-like to humic-like fluorescence was used as a marker of pollution with organic matter from wastewaters [18].

Results and Discussion

Concentrations of ions varied one order of magnitude from time and place during the period of present study. Obvious increasing of ions concentrations and EC was observed downstream places where wastewater discharges were supposed to be or were clearly seen. For example, in waters of the Okhta 2–3 fold increasing of EC (compared to the values in the upstream samples) was observed downstream settlement Enkolovo not far from the boundary of St.Petersburg. Peak of EC (1.4–5 fold increasing) was observed in samples of the Okhta downstream inflow of the Murinsky creek; after that place conductivity decreased due to mixing and dilution with other waters of the Okhta and its other tributaries. As an example data for samples collected in September 2013 are shown at Figures 1 and 2. In Table 1 ranges of values are given for three groups of sampling points (represented as in [18], M notes for the Murinsky creek, O – for the Okhta). Samples of the first group were taken from unpolluted parts of streams that were far from direct canalization outlets. Samples of the second group were taken from possibly polluted or slightly polluted parts of streams, samples of the third group–from definitely polluted parts.

Table 1. Ranges of water parameters. Concentrations are given in mkmol/L, electric conductivity – in mkSm/cm

Samples	$C(K^+)$	$C(Na^+)$	$C(Mg^{2+})$	$C(Ca^{2+})$	$C(Cl^-)$	$C(SO_4^{2-})$	IC	EC
M9p–M10p	50–110	210–390	250–470	610–1065	220–280	310–420	430–2500	110–320
M1–M5	10–160	60–8100	120–790	500–2630	860–15600	200–590	1100–4160	235–1970
M6–M13	20–440	335–4130	150–485	715–1700	2400–7000	430–870	1900–4460	540–1160
O1–O4	15–25	120–200	50–100	90–230	60–160	10–85	220–580	40–75
O5–O9	30–90	250–820	70–205	225–670	350–910	70–290	550–1550	120–250
O10–O17	60–165	480–2520	110–340	340–1200	590–4000	195–690	340–3250	230–725

Seasonal variation of EC and ions concentrations were significant; the values at the same sampling points in the river and the creek differed by a factor of 10 or less. This could be explained by changing of water precipitation and evaporation depending on weather conditions. The data correspond with the figures from observation station Novoye Devyatkino according to which concentrations of main ions changed not more than one order of magnitude during periods of low and high water flow rate [13].

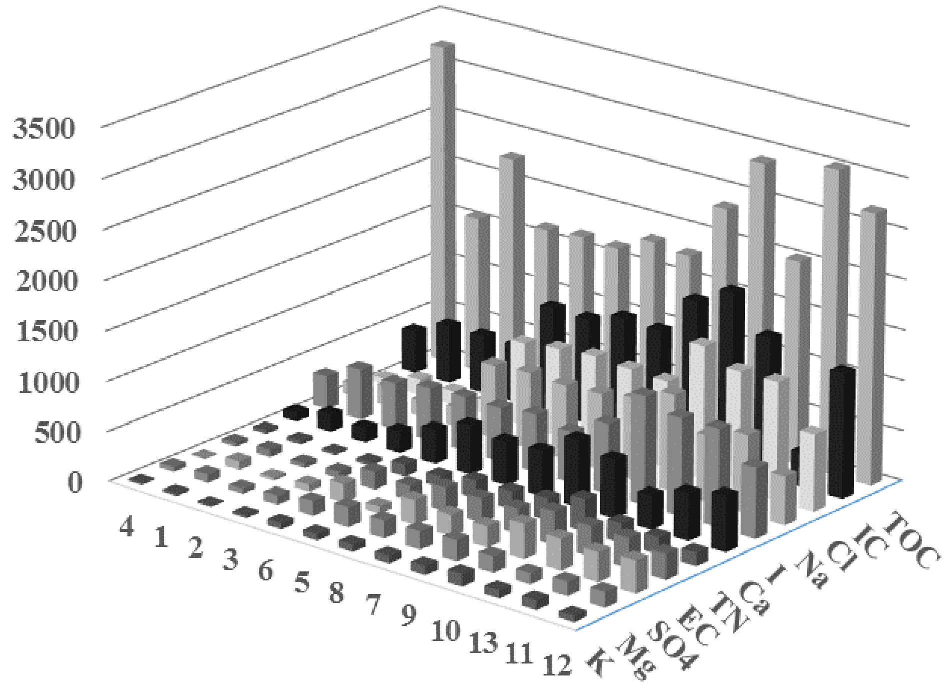

Figure 1. Parameters of water from river Okhta.
Concentrations of ions, TN, TOC and IC are given in mkmol/L, EC in mkSm/cm,
I refers for fluorimetric parameter I 230,350/420 (see explanation in the text),
which value was multiplied by 1000.

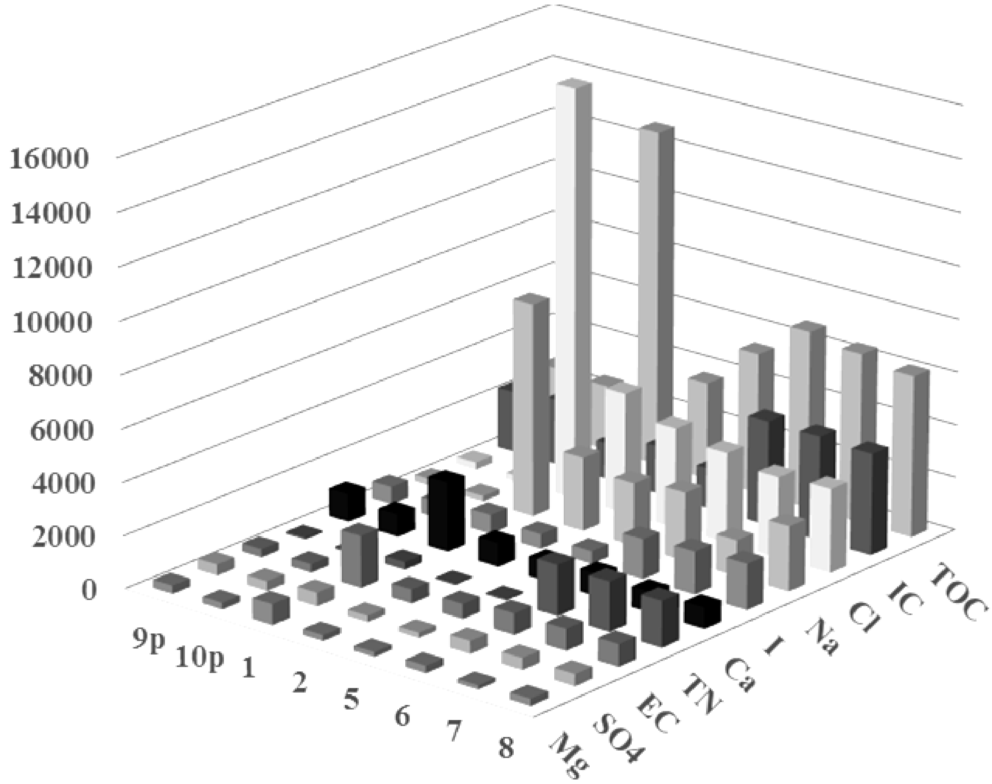

Figure 2. Parameters of water from the Murinsky creek.
Concentrations of ions, TN, TOC and IC are given in mkmol/L, EC in mkSm/cm,
I refers for fluorimetric parameter (I 230,350/420 (see explanation in the text),
which value was multiplied by 1000.

Bondarenko E.A., Il`ina Kh.V., Andrianova M.Ju., Chusov A.N. Main inorganic ions and electric conductivity of polluted urban streams. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 37–44. doi: 10.5862/MCE.68.4

Correlation coefficients r between concentrations of ions and other water parameters related to pollutants from wastewaters were calculated (Tables 2, 3).

Table 2. Correlation coefficients for water samples of the Murinsky creek (n = 32). Concentrations are given in mkmol/L, electric conductivity – in mkSm/cm

Parameter1 / Parameter2	$C(K^+)$	$C(Na^+)$	$C(Mg^{2+})$	$C(Ca^{2+})$	$C(Cl^-)$	$C(SO_4^{2-})$	IC
EC	0.65	0.93	0.70	0.88	0.95	0.60	0.62
TN	0.46	0.20	0.01	0.03	0.09	0.36	0.65
TN/TOC	0.55	0.22	0.04	0.10	0.12	0.52	0.77

Table 3. Correlation coefficients for water samples of the Okhta (n = 30). Concentrations are given in mkmol/L, electric conductivity – in mkSm/cm

Parameter1 / Parameter2	$C(K^+)$	$C(Na^+)$	$C(Mg^{2+})$	$C(Ca^{2+})$	$C(Cl^-)$	$C(SO_4^{2-})$	IC
EC	0.94	0.95	0.86	0.91	0.96	0.91	0.91
TN	0.93	0.80	0.74	0.79	0.78	0.76	0.81
TN/TOC	0.78	0.65	0.69	0.64	0.59	0.54	0.68

The water parameters were chosen according to the following considerations. Increased amounts of organic and inorganic nitrogen compounds are usually present in domestic wastewaters [15, 20]; they are summarized in parameter TN. Presence of organic matter (as TOC) cannot be used to distinguish between natural and wastewaters in the studied streams [18] because of high background content of natural organic matter, such as humic substances [16, 18]. Instead of it, molar ratio of TN to TOC (TN/TOC) is used to distinguish between nitrogen in natural organic matter (in streams) from nitrogen added with wastewaters. It is known that TN/TOC increases in human-disturbed streams and rivers compared to the unpolluted water objects [23].

Data from tables 2 and 3 show that all the studied ions have significant role in increasing of water conductivity in the Okhta and its tributary: correlation coefficients between ions concentration and EC were from 0.60 to 0.95. The data does not allow selecting a certain ion that is more characteristic for pollution than others.

Correlation coefficients with TN or TN/TOC reveal some difference among ions: r was positive in all cases, the highest values were for potassium-ion among cations (from 0.46 to 0.93) and IC among anions (from 0.65 to 0.81). However, in the Okhta waters rather high correlation coefficients were found also for the rest of studied ions (from 0.54 to 0.80). This can be explained by difference in wastewater content, because the Murinsky creek accepts mainly domestic wastewater and the Okhta accepts wastewaters from industrial enterprises. Properties of soils, natural water sources and variation of flow rates in catchment basins also may produce effect.

In order to compare relative concentrations of ions molar fraction of cation or anion among studied cations or anions were calculated according to the formula (1):

$$R_i = (C_i \cdot 100\%) / (C_{sum}) \quad (1)$$

where C_i – molar concentration of cation or anion (mol/L), C_{sum} – sum of molar concentrations for studied cations (K^+, Na^+, Mg^{2+}, Ca^{2+}) or anions (Cl^-, $SO_4{}^{2-}$, $HCO_3{}^-$), correspondingly.

Data for molar fractions in tables 4 and 5 show difference between ions in unpolluted and polluted waters. Growth of EC is followed by increasing of molar fractions of one cation and one anion: sodium (r is 0.65 for the Murinsky creek, 0.61 for the Okhta) and chlorides (r is 0.54 for the Murinsky creek, 0.70 for the Okhta). Molar fractions of potassium has small positive or negative correlation coefficients with EC (r = 0.12 for the Murinsky creek and r = –0.06 for the Okhta). Other studied ions have negative correlation coefficients between their molar fractions and conductivity (r varies from –0.03 to –0.72). These results correspond to the information that sodium-ions, chlorides and hydrocarbonates in general prevail over other ions in domestic wastewater [24].

Correlation between molar fractions and TN was positive for monovalent cations sodium and potassium (see table 4 and 5, r from 0.16 to 0.60). Negative values of r were observed for divalent cations calcium and magnesium (r varied from –0.36 to –0.77), sulfates (r from –0.04 to –0.16). For molar fractions of other ions r had positive or negative values in different streams.

Table 4. Correlation coefficients for water samples of the Murinsky creek (n = 32)

Parameter1 / Parameter2	$R(K^+)$	$R(Na^+)$	$R(Mg^{2+})$	$R(Ca^{2+})$	$R(Cl^-)$	$R(SO_4^{2-})$	$R(HCO_3^-)$
EC	0.12	0.65	-0.66	-0.61	0.54	-0.57	-0.42
TN	0.57	0.35	-0.36	-0.38	-0.15	-0.18	0.26
TN/TOC	0.60	0.36	-0.40	-0.38	-0.14	-0.22	0.27
I 230,350/420	0.65	0.39	-0.46	-0.40	0.02	-0.31	0.12
I 270,350/420	0.51	0.35	-0.41	-0.35	-0.13	-0.26	0.29

Table 5. Correlation coefficients for water samples of the Okhta (n = 30)

Parameter1 / Parameter2	$R(K^+)$	$R(Na^+)$	$R(Mg^{2+})$	$R(Ca^{2+})$	$R(Cl^-)$	$R(SO_4^{2-})$	$R(HCO_3^-)$
EC	-0.06	0.61	-0.72	-0.39	0.70	-0.03	-0.60
TN	0.16	0.60	-0.77	-0.39	0.66	-0.04	-0.56
TN/TOC	0.075	0.63	-0.67	-0.47	0.63	-0.14	-0.50
I 230,350/420	-0.02	0.55	-0.53	-0.42	0.62	-0.12	-0.50
I 270,350/420	-0.21	0.44	-0.32	-0.35	0.46	-0.21	-0.32

The results were also compared with fluorimetric parameters of water (Tables 3 and 4). We used ratio of intensities of two fluorescence types: protein-like fluorescence (that is common for wastewaters) and humic-like fluorescence (that is common both for natural unpolluted waters and wastewaters) [25]. Such ratio increases when domestic wastewaters are discharged to river waters [18, 25]. In Tables 4–5 these ratios are denoted with "Iex, em1/em2", where "ex" – excitation wavelength (230 or 270 nm), "em1" and "em2" – emission wavelengths, "1" notes for protein-like fluorescence (at 350 nm), "2" – for humic-like fluorescence (at 420 nm). Ratios with the chosen wavelengths were most informative in revealing pollution for both studied streams as it was shown in [18, 25].

It can be seen from Tables 4 and 5 that character of correlation of ion molar fraction with fluorimetric parameters is close to correlation with TN, TN/TOC. In most cases correlation coefficients have the same sign (positive or negative). In both studied streams fluorimetric parameter increases together with growth of $R(Na^+)$ and reduction of $R(Mg^{2+})$ and $R(Ca^{2+})$.

Summary

Waters of urban river Okhta and its polluted tributary the Murinsky creek were studied. Concentrations of main inorganic ions K^+, Na^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-} and inorganic carbon were determined together with EC, TN, TOC and fluorimetric parameters of water samples.

Concentrations of all studied ions and EC increased as a result of pollution with wastewaters. The ions concentrations rose together with growth of EC. Correlation coefficients between ion concentration and EC were from 0.62 to 0.96 and it was impossible to select any ion specific for pollution. High positive values of correlation coefficients (0.54–0.70) were found between EC and molar fractions of several ions: sodium and chloride. Correlation coefficients between EC and molar fractions of bivalent cations, sulfates and hydrocarbonates were negative. These data suggest that pollution of river and creek with wastewaters together with general growth of ions concentrations increase also molar fractions for sodium and chlorides and reduce molar fraction for bivalent cations and sulfates. Such effect is a result of difference in ion relative concentration in polluted and unpolluted waters.

Positive correlation coefficients (from 0.35 to 0.63) were found between molar fraction of sodium and parameters connected with pollutants derived from organic matter degradation: TN, TN/TOC, ratio of protein-like fluorescence (excitation at 230 or 270 nm, emission at 350 nm) to humic-like fluorescence (excitation at 230 or 270 nm, emission at 420 nm).

The obtained results support the idea of wastewaters` leading role in EC changing for the studied streams. In general EC can be applied as an express-method for environmental monitoring in the Okhta and the Murinsky creek. Other parameters such as molar fractions of sodium and chlorides can also be informative in revealing pollution with wastewaters.

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Bondarenko E.A., Il`ina Kh.V., Andrianova M.Ju., Chusov A.N. Main inorganic ions and electric conductivity of polluted urban streams. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 37–44. doi: 10.5862/MCE.68.4

doi: 10.5862/MCE.68.5

Hybrid wood-polymer composites in civil engineering

Гибридные древесно-полимерные композиты в строительстве

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Key words: hybrid wood-polymer composites; impregnation; thermosets; glass, basalt, carbon tapes; external and interlayer reinforcing; water-soluble sulfoadducts of the carbon nanoclusters (“Ugleron C”); carbon nanoporous microfibres; EpoxyPAN.

Ключевые слова: гибридные древесно-полимерные композиты; пропитка; реактопласты; стеклянные, базальтовые, углеродные ленты; внешнее и межслойное армирование; водорастворимые сульфоаддукты нанокластеров углерода (Углерон С); углеродные нанопористые микроволокна; ЭпоксиПАН

Abstract. The interest in wood-based materials and structures is increasing every year, and as a result, attempts are constantly being made to modify it, in order to increase mechanical and operational characteristics. In this case the complicating circumstances are the contradiction between the hydrophilic nature of wood and water repellence of the majority of the thermosets that can significantly affect the properties of wooden parts and structures. The paper analyzes the state of research in this area and draws conclusions in favor of methods of wood gradient impregnation with reinforcing water-compatible epoxy thermosets and external as well as interlayer reinforcement of wood structures with high-strength glass-, basalt-, organo- and carbon-fiber ribbons with anisotropic properties. The possibility of modification of water-compatible epoxy polymers by carbon micro- and nanoparticles of new species was also studied. The results of the pilot studies of the wooden details gradient impregnated with the water compatible epoxy compositions modified by sulfoadducts of nanoclusters of carbon ("Ugleron C") and carbon nanoporous microfibers (CNPMF) are given. The possibility and features of external reinforcing of the wooden details by glass ("E" – type fibre), carbon (on the basis of carbon fibers) was considered and the case of the basalt and polyaramid unidirectional tapes was estimated. The technology of the additional strengthening the wooden details by an external membrane from a multifunctional composite water compatible coating – the "EpoxyPAN" was offered. Results of the tests the samples of the wooden details covered with a continuous membrane from "EpoxyPAN" have confirmed the previous assumptions of the prospects of such technology. Thus, the possibility of creation of the hybrid wood-polymer composites (HWPC) of new types is proved and problems of further work are formulated.

Аннотация. Интерес к материалам и конструкциям на основе древесины с каждым годом увеличивается, вследствие чего постоянно предпринимаются попытки ее модификации, для того, чтобы повысить механические и эксплуатационные характеристики. Осложняющими обстоятельствами при этом являются гидрофильная природа древесины и гидрофобность большинства реактопластов, способных заметно повлиять на свойства деревянных деталей и конструкций. В работе проведен анализ состояния исследований в этой области и сделаны выводы в пользу методов градиентной пропитки древесины усиливающими водосовместимыми эпоксидными реактопластами и внешнего, а также межслойного армирования древесных конструкций высокопрочными стекло-, базальто-, органо- и углеволокнистыми лентами с анизотропными свойствами. Проведено также изучение возможности модификации водосовместимых эпоксидных полимеров углеродными микро- и наночастицами новых видов. Приводятся результаты экспериментальных исследований деревянных деталей, градиентно пропитанных водосовместимыми эпоксидиановыми и эпоксиноволачными композициями, модифицированными сульфоаддуктами нанокластеров углерода («Углерон С») и углеродными нанопористыми микроволокнами (УНПМВ). Одновременно рассматривается и оценивается

Пономарев А.Н., Рассохин А.С. Гибридные древесно-полимерные композиты в строительстве // Инженерно-строительный журнал. 2016. № 8(68). С. 45–57.

возможность и особенности внешнего армирования деталей из древесины стеклянными («Е»-стекло), углеродными (на основе углеродных волокон Т-700), базальтовыми и полиарамидными однонаправленными лентами. Предложена технология дополнительного усиления деревянных деталей внешней мембраной из многофункцинального композиционного водосовместимого покрытия «ЭпоксиПАН». Результаты испытаний образцов деревянных деталей, покрытых сплошной мембраной из «ЭпоксипАНа» подтверждают сделанные предположения о перспективности такой технологии. Таким образом, обоснована возможность создания гибридных полимерно-древесных композитов (ГПДК) новых видов и сформулированы задачи дальнейшей работы.

Introduction

The first impregnating structures increasing not only fire – bioprotective, but also physics and mechanical properties of wood have appeared at the beginning of the XX century. In 1909 the Belgian chemist and the inventor Leo Bakeland have synthesized the first synthetic thermosetting polymer, received at the initial stage of synthesis of phenol formaldehyde resin which called "Bakelit" [1]. A little bit later in Russia its analogs have been synthesized – carbolit [2, 3] (in 1914), and in the early twenties – bazilit – antiseptics on the basis of dinytrophenol, possessing the strengthening action [3] which have found broad application in the industry of that time. Bakelite wood was widely used in aircraft industry, shipbuilding, mechanical engineering, etc. and is still applied.

Now the choice of structures for increase of physics and mechanical characteristics of wood is much wider [4, 5]. In this connection it is necessary to prove criteria of choice of the optimal variants. These criteria can be shared conditionally into two groups: operational and technological. Among technological parameters the most important is the possibility of solving the contradiction between hydrophilic of wood and water repellency of the majority of high-strength polymer compositions.

Table 1. Comparative characteristics of the strongest polymers which can be used for the physics and mechanical modification of wood [6–13]

№	**Type of polymer**	**Dencity, g/cm³**	**Tough-ness kJ/m²**	**Pressure Strength, MPa**	**Tension Strength, MPa**	**Elasticity module MPa**	**Viscosity in uncured form, MPa•c**	**Brake Elongation, %**
1	Phenol-formaldehyde	1.25–1.38	10–20	90–150	50–100	1800–2300	90–1200	1.2–3
2	Melamine	1.45–1.6	2.5–6	150–200	55–98	5000–5500	150–1000	0.8–2.9
3	Epoxy	1.16–1.25	12–25	160–300	80–140	2500–3500	1000–7000	2.5–4.1
4	Epoxy novolac	1.33–1.47	12–15	120–130	85–93	2000–2700	500–40000	3.8–4.1
5	Polyester	1.215	0.75	160	65	3000	900–1000	2.5
6	Vinylester	1.1–1.25	13–24	35–50	90–146	2300–3600	450–750	2.1–15
7	Methacrylate	1.17-1.2	9–13	120–160	80–140	3000–3500	500–2500	0–0.5
8	Polyvinyl alcohol	1.2–13	4–120	24–140	63–120	1400–6000	5–45	0–3

Derivations from Table 1:

In spite of the fact that the nomenclature of various synthesized polymers is very big now, the majority of them are almost not applicable for impregnation of the wooden details. The main reasons – insufficiently high physics and mechanical and other operational characteristics, and lack of a possibility of creation the water compatible compositions on their basis with high level of penetration. All the thermosetting polymers demanding high temperatures and pressure for it processing are also automatically excluded from the perspective directions also. From all considered and selected options epoxy compositions are of the greatest interest on condition of solution the problem of their water repellency.

One of the technologically attractive opportunities of increasing physics and mechanical characteristics of many thermoreactive polymers is their modification with small amounts of special types of carbon nanoparticles [14–25]. At the same time the possibility to preserve low viscosity of the impregnating structures is supposed to exist and is already proved to considerably improve their physics and mechanical characteristics and increase durability.

Ponomarev A.N., Rassokhin A.S. Hybrid wood-polymer composites in civil engineering. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 45–57. doi: 10.5862/MCE.68.5

However, impregnation and polymerization of the impregnating structures themselves cannot provide the highest increase of physics and mechanical characteristics of wood. The required results can be reached by combining impregnation with reinforcement of wood polymers by high-strength polymeric composites on the basis of fabrics and tapes made from "E" – glasses, basalt, carbon and poliaramid fibers. Listed polymer composite materials can have very high physics and mechanical characteristics themselves, but their wide use is seriously limited by its high price. Cheaper analogs with the lower cost but comparable properties are essential for practical application in construction. Results of comparison of the conditional prices for the unit mass of composite production for the different types and metal details of the same sizes are given in Figure 1.

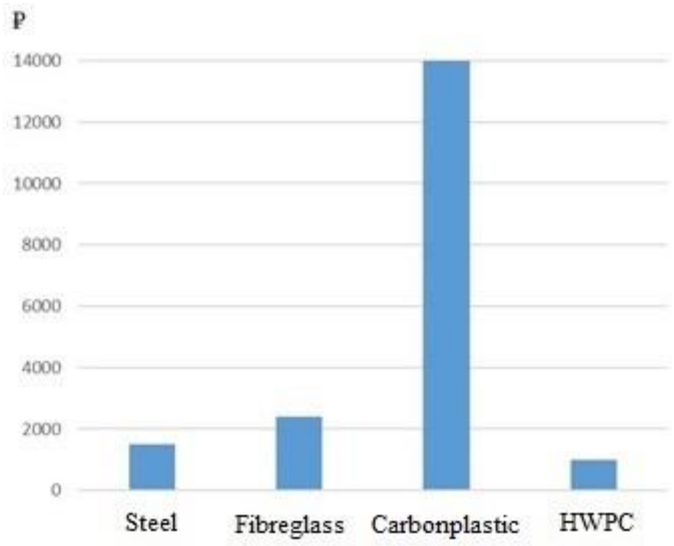

Figure 1. Comparative conditional price of all-metal and composite details with the size 30x100x1000 mm

Prospects of developments and production of hybrid wood polymeric composites (HWPC) follow from this comparison evidentially. However, the problem of increasing the HWPC physics and mechanical characteristics to the level of the corresponding values received for monolithic carbonplastics and separate types of fibreglasses remains unsolved.

In construction the method of external reinforcing of various details by carbon fabrics have been successfully proved in practice. This method has been applied to strengthening of reinforced concrete structures for a long time [26]. The same approach brings possibilities of the strengthening the structures on the basis of wood and develop the new types of HWPC.

Such attempts were made numerously. In 1965 the American engineer Evangelos John Biblis has reported to discover potential possibility to use flat fittings from fiber glass for strengthening wood details [27]. But at that time it was difficult to carry out complex tests due to the lack of the industrial materials suitable for external reinforcement of wood and high-quality glues.

Nearly 30 years later, in the 1990-th this topic has been raised again by group of scientists N. Plevris, N. Deskovic and T. Triantafillou [28–31], as the industrial market featured a wide choice of reinforcing materials and high-quality glues. For example, the unidirectional carbon tapes 0.55–0.77 mm thick were pasted as a way to reinforce wooden beams externally by means of epoxy glue. Tests have shown the increase in durability by 20–40 % comparing to rather similar beams without external reinforcing. There was no rupture of the carbon tapes, however there was a cohesive destruction of wood or destruction of glue connection. H. Dagher [32] arrived at the same results.

The influence of degree of humidity of wood was important [33, 34]. Well dried wood (5–7 % of humidity) showed better results than a damper one as these cases showed the best adhesion to glue structures of system of external reinforcing. Final durability also depended on the amount of natural defects (knots) on wood preparation [35].

The obvious results of improvement of the strengthened wood structures properties have set up the field of application of composite materials: repairing of the wooden beams [36, 37], restoration of monuments of wooden architecture [38–40], bridge building [41, 42]. The area of application defined the best options of external reinforcing or strengthening were developed: reinforcement of all surface [43, 44], bearing surface area [40, 44], places of a break [45], winding [46]. Also there were created and investigated options of high-strength materials for external reinforcing: unidirectional carbon tapes or polyaramid fibers (average increasing of the durability was 30–40 %), fiber glass fabrics or basalt tapes (average increasing of the durability was 15–30 %) [29, 38, 43, 45, 47–49].

Reinforcement by the different fibers is possible not only for integral details, but also for improvement of quality of seams of the glued wood [50, 51]. Usage of the reinforcement increases durability at a bend for 26–51 % depending on the amount of the reinforcing material and the way of his injection [52]. Usage of carbon fiber or fiberglass cores and lamels for creation of tongue-and-groove connections [53, 54] is also shown.

Pretension of carbon tapes in a beam by means of metal anchors can be created in order to reduce a deflection of wooden beams [55].

Economic prospects of implementation of HWPC were considered in the work of F. Taheri, M. Nagaraj and P. Khosravi [56]. These authors observe lower price of HWPC due to mass production and optimization of cross section of details. Undoubtedly postponed economic effect must also appear due to increase of durability of HWPC.

There are also opposite opinions. For example, Y. Kim and K. Harries [57] do not exclude isolated cases of application of hybrid wood and polymeric composites (reconstruction of monuments of wooden architecture, etc.), but exclude mass character as, in their opinion, it will be impossible to increase their bearing ability more than for 40 %. Even if external reinforcement will make it possible to resist heavy loads, bearing strain or cohesive destruction of the main body of wood will happen.

The results of the carried-out analysis suggest that it is possible to define the main directions of development of hybrid wood and polymeric composites:

– the choice of optimum materials for impregnation into the precursors of HWPC, the most corresponding on economic, physics and mechanical and operational indicators, capable to considerably increasing the strength of the wood and to give it ability to resist bearing strain and cohesive destruction;

– development of technology for gradient impregnation into the precursors of HWPC with the purpose of improvement of physics and mechanical characteristics and achieving the maximum adhesion to the external reinforcing layer;

– the choice of materials of external reinforcement, the most corresponding on economic, mechanical and operational indicators.

– constructive and technological development the processes of manufacturing the HWPC.

Relatively recently – in year 2000 the results of work on bulk impregnation and the subsequent polymerization of the resins impregnating wood for the increase of physics and mechanical characteristics of wooden details have been published [58]. In this work the bulk impregnation of wood by phenol formaldehyde, melamine and urea-formaldehyde was carried out. These resins after hardening have provided the increase of durability of wood on compression for 33–35 %, on a bend – 12–20 % and increase in the module of elasticity by 5–12 %, though the expense of the impregnating compositions was rather high, which has considerably worsened prime cost indicators. Certain works describe first attempts to use epoxy compositions [59], and also water compatible epoxy compositions [60]. However, the data about the application the water compatible epoxy compositions have modified by some nanoparticles for this purpose are not revealed now in the considered references. It can be considered as a serious gap as injection of carbon micromodifiers of fulleroid type into the water compatible epoxy compositions, furthermore makes it possible to raise dramatically operational resource of this material and to considerably increase durability of the designs created from HWPC that is extremely essential in construction.

Materials and methods

According to the planned researches, the bending strength of samples of the HWPC compared to samples of raw wood, the standard preparations have been made of timber of coniferous breeds by the sizes of 80 x 80 x 1600 mm and 20 x 40 x 800 with humidity no more than 10–12 % in total of more than 40 pieces for ensuring statistical reliability of the results of the tests. After preliminary drying of industrial wood in a drying chamber within a regular production cycle of a woodworking and production of the standard preparations of the required shape by method of mechanical milling, drying of preparations was continued for about 25 days indoors with the heated floors without access of damp air. Additional drying was necessary to provide the best possible results of tests of template matching made of basic wood without some subsequent processing and also is expedient for the best interaction with samples of

HWPC with the impregnating structures on a water basis. "E-glass" TC6-11-380-76 has been chosen as the system of external reinforcing differing in the minimum cost, but possessing the acceptable strength variables for experimenting fibreglasses based on T-25 fabric with a calico weave (Amendment 1-12). Preliminary two-phasic processing of the dried-up samples by water-soluble epoxy structure of "EpoxyPAN-primer" TC 23 1253-053-91957749-2011 was carried out in order to improve adhesion of the reinforcing layers of T-25 fabric to wood and the general increase of physical and mechanical characteristics of these samples of HWPC too. The samples were made with a rough of the prepared surface. The possibility to increase the physical and mechanical characteristics of polymer matrices of the composite materials by method of their modification by insignificant amounts of sulfoadducts of carbon nanoclusters ("Ugleron C") [61] and carbon nanoporous microfibers (CNPMF) [62] was studied in order to choose and optimize impregnating and the subsequent glue structures. Modification was made by method of injection of several various concentration of carbon micromodifiers into the hardener with the subsequent careful hashing of the hardener with the micro modifier, the following mixture of a hardener with state standard specification 10587-84 ED-20 epoxy and filling of shapes in the cylindrical shape with a diameter of 40 mm and a height of 40 mm. 8 samples were made for ensuring the maximum reliability of the test results for each concentration of the micromodifiers. At the determination of pressure strength, it has provided further for all values of concentration the level of sizes of confidential intervals which is not exceeding 5 % is relative to the set confidential probability 0.95.

After full polymerization of samples was finished, the faces of cylinders were cleaned and samples were located between plates of a hydraulic measuring press WK18 (Figure 2). By the results of the tests schedules of concentration depending on the pressure strength and the amount of the micromodifiers, the optimal meaning of its concentration was determined. This optimal concentration was taken further for introduction into the polymer matrix of the strengthening layer decided on T-25 fabric.

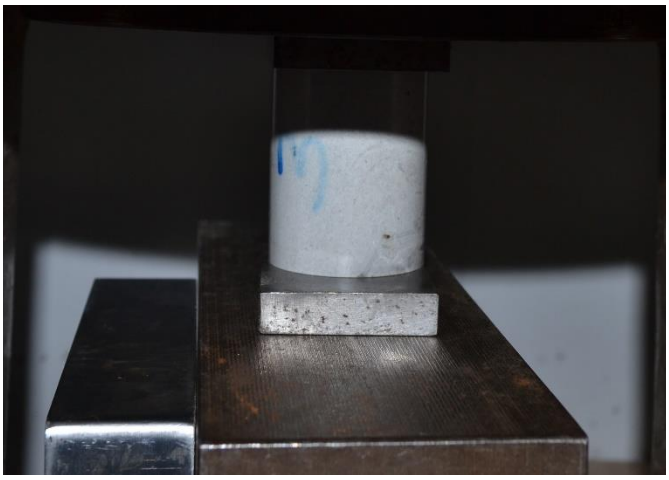

Figure 2. Tests of a sample of the modified polymeric matrix for durability at compression on the press of WK18

At the subsequent production of test samples of HWPC, the chosen concentration of carbon micromodifiers was entered into the "EpoxyPAN-primer". It was done with the glue for fastening of the strengthening layer by the same way.

After the full polymerization of the impregnating structure which is carried out under normal conditions at a temperature of 30 ^{O}C, external reinforcing of preparations by two layers of T-25 (VMP) fabric-78 with a calico weave from "E" – TC 6-11380-76 glasses (with amendment 1-12) method of vacuum molding on two opposite parallel sides of preparations was carried out. As glue structure the composition from 53 % mass. of epoxy resin ED-20 (Russian State Standard 10587-84), 47 % mass. of water soluble amine hardener was used. The water soluble amine hardener has been modified by carbon nanoporous microfibers (CNPMF) in number of 0.8 % of mass. relatively the mass of the hardener.

Upon completion of polymerization process of glue connection, the continuous membrane from polymer nanocomposite material EpoxyPAN was applied on an external surface of preparations for additional strengthening of HWPC and protection against possible action of hostile environment, water and fire (Fire technical characteristics of EpoxyPAN, according to the existing certificate: G1, If1, Sp1, Fo2, T1). Drawing was made by a pneumatic method by means of the textural sprayer the LC-02 brand PRAKTIKA Ltd company.

The first stage of examination of test samples of HWPC for durability on stretching at a bend included tests of small-sized samples of HWPC the sizes 20 x 40 x 800 and control of the row wooden models of comparison of the same sizes on a three-point bend. Tests were carried out in accordance with Russian State Standard 16483.3-84. on a hydraulic press of PSU-50.

At the second stage of tests, measurements of durability on a tension strength of samples of HWPC of the large-size sizes (80 x 80 x 1600) and control models of comparison from a wooden bar of the same form on a four-dot bend in accordance with Russian State Standard 16483.12-72 have been taken. Tests were carried out at the stand with the hydraulic test BISS MAGNUM UT-05-3000 module. For a possibility of carrying out tests of samples of the above-stated sizes the industrial technological equipment which drawing is given in Figure 3 has been developed and has been made.

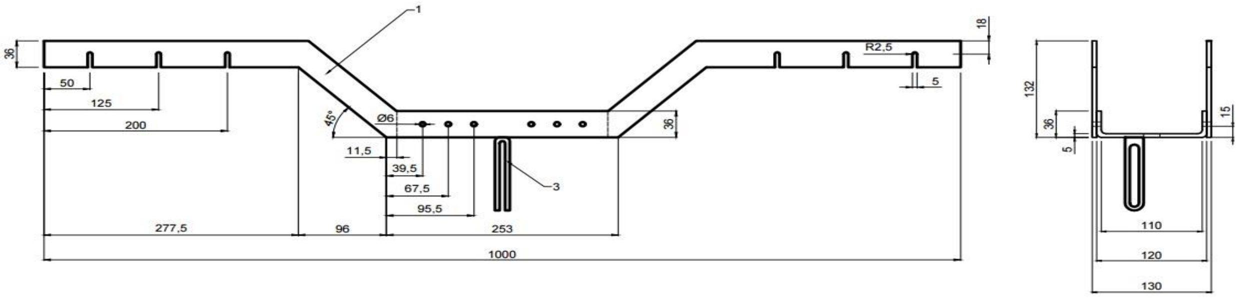

Figure 3. Drawing of the industrial technological equipment

The scheme of loading of the studied samples and pictures of test process are given in Figures 4 and 5 respectively.

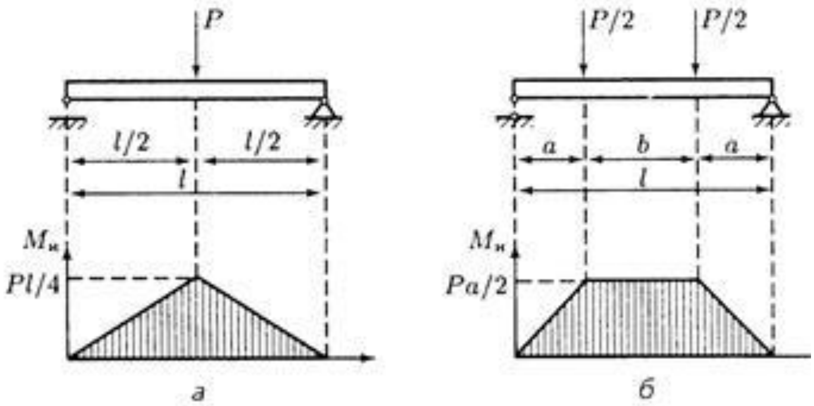

Figure 4. Schemes of loading of the samples at three - and a four-dot bend

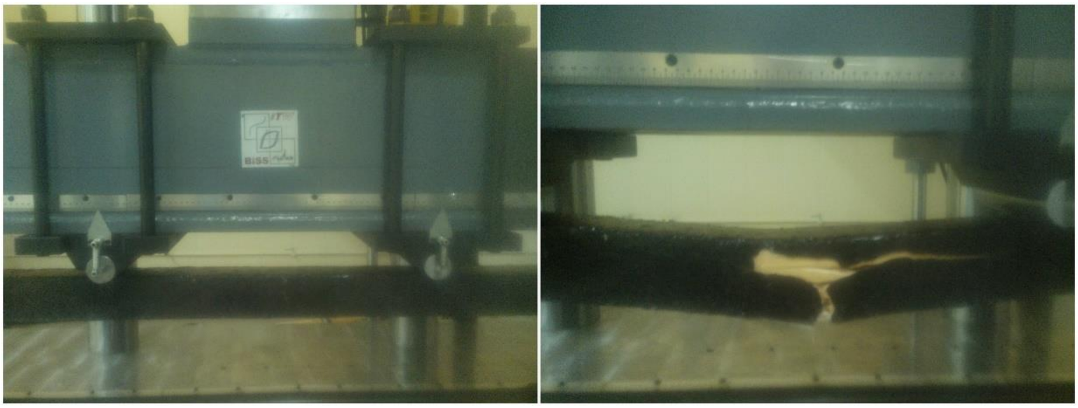

Figure 5. Tests of samples of HWPC and models of comparison by the sizes 80 x 80 x 1600

Ponomarev A.N., Rassokhin A.S. Hybrid wood-polymer composites in civil engineering. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 45–57. doi: 10.5862/MCE.68.5

Results and Discussion

Results of researches of the dependence of the durability of a polymeric matrix from the concentration of two types of the carbon micromodifiers entered into it structure are presented on the graphs (Figs. 6 and 7).

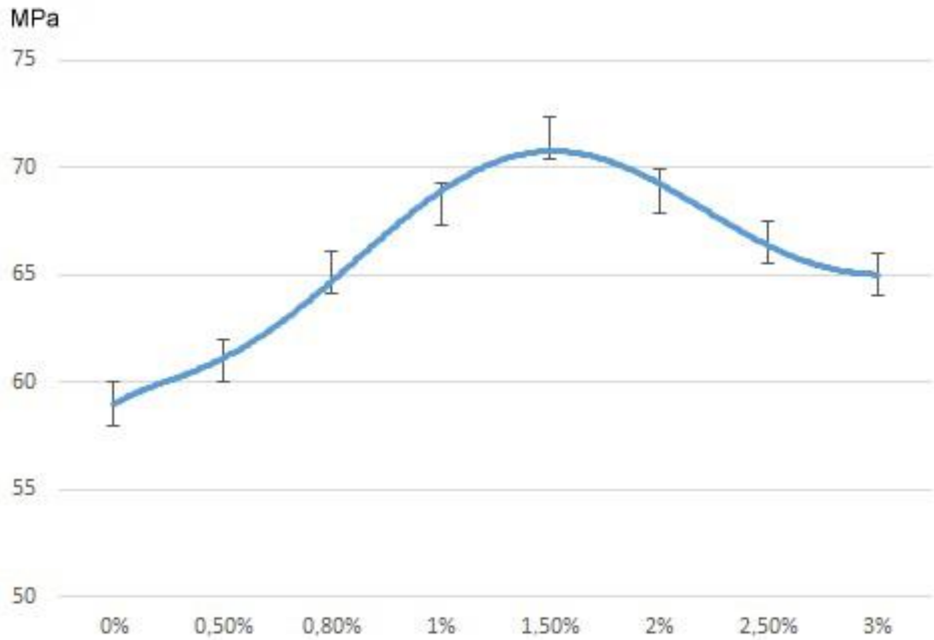

Figure 6. Dependence of the durability on the pressure strength of the test samples of epoxy polymer from the concentration of "Ugleron C"

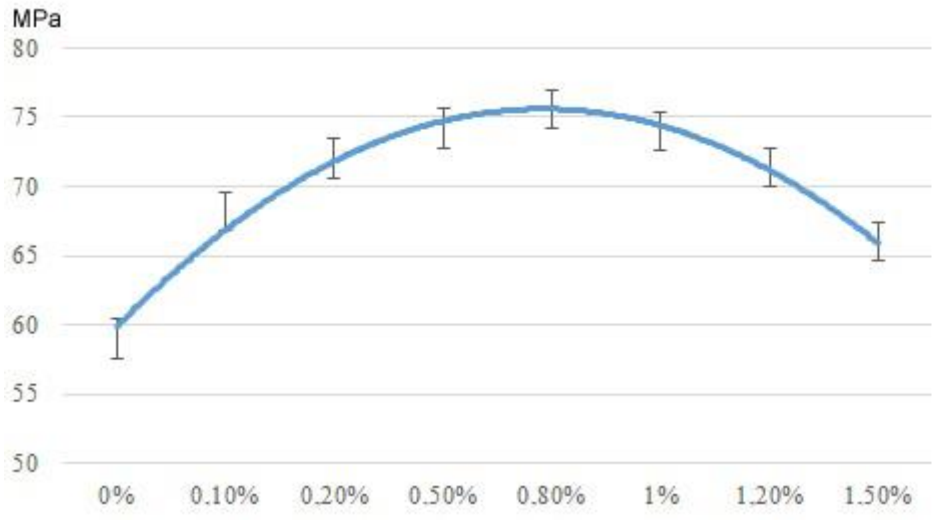

Figure 7. Dependence of durability on the pressure strength of the test samples epoxydean polymer from the concentration of the CNPMF

From the obtained data, it follows that optimal concentration for the entered sulfoadducts of carbon nanoclusters ("Ugleron C") are the values of 2 % mass, relatively the mass of a hardener and 0.8 % mass, for the CNPMF. The maximum values of increase of durability of samples of polymeric matrixes on pressure strength have made 21 % and 31 % respectively. According to the achieved results, the most effective type of micromodifier has been chosen and it was entered into composition for impregnation and into glue structure for vacuum formation of the strengthening HWPC of layers of T-25 (VMP) fabric-78 with a calico weave.

Tests of small-sized samples (sizes of 20 x 40 x 800 mm) have shown increase in durability at stretching at a bend on average for 100 %. Results of tests of full-scale samples (sizes 80 x 80 x 1600) have shown increase in durability at a bend at 18 % and increase in Young's modulus for 14 %.

Results of tests of the modified polymeric matrix and results of tests of samples of HWPC have been processed according to recommendations Russian State Standard 8.207-76 "Processing of results of measurements with repeated supervision" also correspond to values of the relative error of average values of these sizes which is not exceeding 5 % at confidential probability 0.95.

The analysis of results and studying of nature of samples destruction (Figure 8) show that at external reinforcing of wooden preparations by T-25 (VMP) fabric-78 the strengthening of the samples has practically not happened and observed increase in durability is caused only by resistance to destruction of an external "EpoxyPAN" membrane. It will be coordinated with the data of preliminary experiments on tests of the standard samples of wood beams and cubes (tested in accordance with Russian State Standard 16483.3-84) which were also strengthened by means of external membranes from "EpoxyPAN". It was founded early, that by using "EpoxyPAN" it is possible to increase the pressure strength of wooden details with the "EpoxyPAN" membrane more, than 60 %.

Thus, it is established that T-25 (VMP) fabric – 78 with a calico weave is not priority material for use as material for the external reinforcing of extended wood preparations and production of high-strength HWPC. Strengthening of details full-strength fabrics can be recommended only for strengthening of details with isotropic properties (panels, boards, etc.).

Figure 8. Nature of destruction of a sample of HWPC at limit loading by a four-dot method. Reinforcing fabric stretched, and the EpoxyPAN membrane collapsed

Such conclusion follows from the fact that when loading extended samples of HWPC the T-25 fabric firstly was extended and guided, without exerting at the same time impacts on mechanical properties of the extended parallel piped at his stretching (at a bend) and was broken off only when strength of a basis of HWPC has been already actually passed.

Thus, it is expedient to recommend use of the unidirectional tapes for strengthening of extended wooden beams, which are desirably high-strength carbon fibres.

It should be noted that, proceeding from nature of destruction of numerous samples of HWPC, on strength indicators strong impact is exerted by existence of knots and cracks on a wood basis, and also as already it has been stated above, its humidity.

The vast majority of the researchers [36–49] consider the HWPC are only the alternative to wooden details. We consider that the scope of the HWPC is much wider. And it can be applied in a number of tasks instead of fiberglass, carbon composites, metal etc.

The vast majority of the researchers consider also, that he more expensive cost of the HWPC in comparison with the wooden details hinder from it wide using [56]. But by our opinion, scope of the HWPC is not limited of the scope of the wooden details. HWPC are capable to replace metal, fiberglass, carbon composites and a coal plastic construction, whose costs are significantly higher, than the HWPC cost (Figure 1).

Comparatively with all the previous known results [36–57] it was founded now in this work, that the durability of the impregnated wood beams (for example) possible to be improved more, than 40 % limit.

Especially, if the external reinforcing will be made by the carbon tapes, the impregnation technology will include the CNPMF doping and the external EpoxyPAN membrane will be used together with all the other methods of improving the durability of the HWPC.

Conclusions

The analysis of literary data has shown that hybrid wood polymeric composites (HWPC) are the perspective materials in view of the acceptable level of their prime cost and potential durability, but demand the improvements of their physical and mechanical characteristics.

The pilot studies executed in the real work have shown that an effective method of increasing the general durability of HWPC is the modification of a polymeric matrix for the fiberglass and for the carbonplastic, the impregnating structure and glue compositions by the carbon micromodifiers – sulfoadducts of the carbon nanoclusters ("Ugleron C") and carbon nanoporous microfibres (CNPMF).

It is established that in concentration dependences of durability of a polymeric matrix on the pressure strength from the mass number of carbon micromodifiers there are maxima: for sulfoadducts of the carbon nanoclusters – with 2 % mass. relatively of the hardener mass, for CNPMF – with 0.8% mass. relatively of the hardener mass.

It is established that for epoxy polymeric compositions of impregnating structure and glue connections at their modification by means of sulfoadducts of nanoclusters of “Ugleron C” carbon and CNPMF increase of durability on the pressure strength respectively for 21 % and for 31 % is possible.

It is confirmed that drawing on a surface of HWPC of a continuous membrane from "EpoxyPAN" gives the increasing of the durability of the studied samples on stretching at a four-dot bend on average for 18 % (and increasing the compressive strength for more than 60 %).

Together with the polymer matrix of composite reinforcing have been modified by CNPMF and “EpoxyPAN” coat, both method of improving the pressure and bending strength of the HWPC lead to 1.5 more time increasing the durability of the HWPC (against maximum 35 %, that was founded for improving the pressure strength in the works, early published [58])

It is defined that, achievement of the increased values of physical and mechanical properties of details from HWPC requires providing the following conditions and permission of the following tasks:

– use as material for external reinforcing of extended details from HWPC of the unidirectional high-strength carbon tapes or other high strength tapes. It will allow arising considerably the level of values of physical and mechanical characteristics of HWPC (together with the improved technology of impregnation of wood which has to increase wood resilience to bearing strain);

– the choice of structure of impregnation for the nanocomposite material "EpoxyPAN-primer" and for the main material "EpoxyPAN-coat", as protective membrane as they have successfully proved when carrying out tests of the studied test samples, and also thanks to their good compatibility with hydrophilic wood;

– working off the technology of compulsory gradient impregnation of wood preparations of HWPC by water-soluble and water compatible polymer structures, including research of methods of vacuum and ultrasonic impregnation. It will allow reaching the biggest hardness of near-surface layers of wood preparation, and also will allow avoiding too wide spacing of properties of the raw wood.

Acknowledges

Authors express profound gratitude to the Advisor of director general of JSC SIU “FIBREGLASS” Ph.D. V.I. Natrusov for the given methodical help and to the staff of test center SPSUACE for assistance in carrying out the tests.

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doi: 10.5862/MCE.68.6

Renovation need for apartment buildings in Latvia

Необходимость реновации жилых зданий в Латвии

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Key words: Latvian building stock; apartment buildings; energy efficiency; energy audit; ventilation

Ключевые слова: жилищный фонд Латвии; многоквартирные здания; энергетическая эффективность, энергетический аудит, вентиляция

Abstract. Residential buildings in Latvia are one of the essential heat consumers during the heating season. The majority of Latvian as well as European residential buildings were constructed within the period from 1965 to 1990. Introduction presents brief overview of current situation in Latvian and EU countries. This chapter provides overview of real energy consumption and definition of buildings technical conditions. Materials and methods are based on evaluation of standardized energy consumption in two kindergartens and multi apartment buildings including also dynamic energy simulation. Chapter on thermal performance of building envelope provides an extensive comparison of heat transfer coefficients in non-renovated buildings as well as comparison with normative values. Section on energy consumption of existing multi apartment buildings presents review of buildings real energy consumption before and after renovation. In addition this chapter evaluated indoor air quality. This study was done in order to define necessary reconstruction goals to reach European Regional Development Fund project "A New Concept for Sustainable and Nearly Zero-Energy Buildings" Nr. 1.1.1.1/16/A/007 main targets.

Аннотация. Жилые здания в Латвии являются одним из основных потребителей тепла в отопительный сезон. Большинство латвийских и европейских жилых зданий были построены в период с 1965 по 1990 год. Введение представляет краткий обзор текущей ситуации в Латвии и странах ЕС. В этой главе представлен обзор реального потребления энергии и определение технических условий для зданий. Материалы и методы основаны на оценке стандартизированного потребления энергии в двух детских садах и многоквартирных домах, включая также динамическое моделирование энергии. В главе, касающейся тепловых характеристик ограждающих конструкций зданий, дано подробное сравнение коэффициентов теплоотдачи в не отреставрированных зданиях и сравнение их с нормативными значениями. В разделе об энергопотреблении существующих многоквартирных домов представлен обзор реального потребления энергии зданиями до и после модернизации. Кроме того, в этой главе дается оценка качества воздуха в помещении.

Introduction

Residential buildings in Latvia are one of the essential heat consumers during the heating season. In 2008 the residential sector in Latvia has consumed 74 % of all amount of produced heating energy. The majority of residential buildings were constructed within the period from 1965 to 1990. The importance of urgent need for renovation of existing building stock was highline in several independent studies [1, 2]. These studies evaluated complex approach for retrofitting of multi apartment buildings with a focus on sustainable development at district and national level, similar to research [3, 8] data. It should be mentioned that renovation of existing building stock became an actual problem in EU and other countries as well [6, 9, 12]. In general, existing building stock i classified as post II word war, before II word war and modern building stock build after mid1990ies. It is vitally important to make proper classification of building stock in order to choose most optimal and cost efficient renovation solution. The building built before II word has a completely different construction solution and technical conditions which require more detailed and specific selection of renovation package [14, 21]. This study is focused on analysis post II word war building stock as most cruitial energy consumer. Application of renovation packages can provide a significant reduction of energy consumption by existing building stock (10, 16, 17).

According to the data of Statistical Bureau of Latvia, the residential building construction may be subdivided in the following basic categories:

•Pre-war construction (till 1945);

•Post-war construction (from 1945 to 1991);

•New construction (from 1991);

Number of dwelling according to construction period is shown in Table 1.

Table 1 Number of dwelling according to construction period

Year of construction	Single family houses	Two apartments houses	Terraced house	Multi apartment buildings
<1945	97737	3406	2278	120218
1945–1960	38047	2503	912	49248
1961–1970	26152	1081	536	141169
1971–1980	27018	1081	677	180749
1981–1990	35856	563	340	162723
>1991 (2011)	43846	1826	1509	51268

According to the Table 1 data, share of multi apartment buildings constructed between 1945 and 1990is is 54 % of total number of dwelling buildings. During the pre-war period mainly capital brick buildings and low-storey wooden buildings were built. Both furnace heating and central heating systems were used to heat buildings. In subsequent years these buildings have been gradually connected to the central heating system. It should be noted that unfortunately the majority of these buildings are in a bad technical condition at present.

From 1945 to 1991 mainly typical multi apartment buildings were constructed. Types of buildings 103, 316 and 467 series were among the most widespread. There are approximately 38933 multi apartment buildings in Latvia. The standard thermal conductivity for exterior brick walls was in average 1.33 W/(m^2·K) and for exterior expanded-clay concrete walls – 1.20 W/(m^2·K), which is at least 3.5 times higher than the values specified in the current Latvian Building Code LBN 002-15 “Thermal performance of building envelope” [3] which is valid in Latvia. The largest part of residential buildings (89 %) is privately owned, 11 % belong to the state and self-governments and 2 % belong to apartment cooperatives. The residential building stock of Latvia is represented mainly by one and two-room apartments.

The common problems for existing building stock include non-insulated or partly insulated heating and hot water piping systems, poor thermal properties of building envelope as well as balancing problems due to applied one-pipe heating system. In addition, the heating elements don’t have individual regulation possibilities that cause overheating in kindergartens where temperature reduction by window opening is limited.

The average annual specific heat consumption for space heating of Latvian dwelling buildings is 104.40 kWh/m^2 and for hot water supply – 73.30 kWh/m^2 [2]. The main source of heating in Latvia is provided by district heat supply systems. Totally about 65 % of the housing stock is connected to district heating. The specific heating energy consumption in Latvian kindergartens is estimated to vary between 196 and 285 kWh/m^2. Therefore to reduce energy consumption to meet the municipality’s goal of 100 kWh/m^2, even further actions should be taken, e.g. including, education of kindergarten personnel, HVAC system retrofit and use of high-efficiency HVAC equipment. Almost all renovated building can be found on on-line map.

Map provides also short description of implemented measures and expected energy reduction. The total number of already renovated multi storey buildings in Latvia had reached 711 as on year 2016.

These numbers show the high interest in refurbishment process which is stimulated by the possibility to attract European funds.

Materials and methods

Evaluation of existing multi apartment buildings energy efficiency is based on analysis of real measured data on heat consumption and theoretical calculations using IDA-ICE and RISUKA.

The existing buildings' energy certification scheme is based on unique rating criteria – standardized annual specific heat consumption, which is calculated on the basis of real measured heat consumption for space heating and hot water supply.

The measured heat consumption was recalculated to standardized annual specific heat consumption:

$$q_{st} = \frac{q_h DD_{st}}{DD}, kWh/m^2 \quad (1)$$

where: A – heated built-in area, m^2; DD – degree-days of heating period in rating year; DDst – degree-days of standard year in favorable economic conditions; $q_{s.h.}$ – measured consumption in analyzed year, kWh/m^2 year.

Degree day is widely used to evaluate energy consumptions under different climatic condition [20]. The chosen cases include two kindergartens and multiapartment buildings. The renovation package for both kindergartens as well as for residential building included similar improvements to building facades, as well as heating and ventilation systems. In all cases facades were insulated with additional 100 mm of insulation, also the windows were changed to double glazed PVC windows, additional insulation on pipelines was placed, the radiators were replaced and system was rebalanced. The old one-pipe heating systems with old cast iron heating elements were completely replaced with two-pipe newly built heating system with panel type radiators equipped with thermostatic valves.

Thermal performance of building envelope

In Latvia, the greatest part of residential buildings falls on series 103, 316 and 467, the total space of which is 16801 thousand m^2. The standard heat transfer coefficients for exterior brick walls was in average 1.33 $W/(m^2{\cdot}K)$ and for exterior expanded-clay concrete walls – 1.20 $W/(m^2{\cdot}K)$, which is at least 4.5 times higher than the values specified in the current Latvian Building Code LBN 002-15 "Thermal performance of building envelope" which is valid in Latvia [11].

Despite of the fact that buildings of various types differ visually, the internal engineering and technical structure of all buildings is practically the same in all types of buildings.

Till 1960 mainly calcium-silicate brick buildings were constructed, but at the end of 1960 they started to construct panel buildings. Practically all buildings were connected to the territorial centralized heating system.

The comparison of existing heat transfer coefficient and normative values for common multi apartment building in Latvia is shown in Table 2.

Table 2. The comparison of existing heat transfer coefficient and normative values for common multi apartment building in Latvia

Project type	Type of envelope	U_{real}, W /m^{2}K
103	Roof	0.75
	Aerated concrete panel wall	0.89
	Brick wall	1.27
	Basement ceilings	1.03
	Window	2.56
318	Attic ceiling	1.46
	Brick wall (1)	1.25
	Brick wall (2)	1.32
	Basement ceilings	1.16
	Window	2.56
464	Attic ceiling	0.81
	Externalexpandedclay aggregate panels	1.48
	Basement ceilings	1.33
	Window	2.56
467/5	Attic ceiling	1.54
	Expanded clay aggregate panel wall	1.48
	Basement ceilings	1.49
	Window	2.56
602/9	Attic ceiling	0.8
	Expanded clay aggregate panel wall	1.48
	Basement ceilings	1.14
	Window	2.56

Comparison of U-value for residential buildings in Latvia is shown in Figure 1.

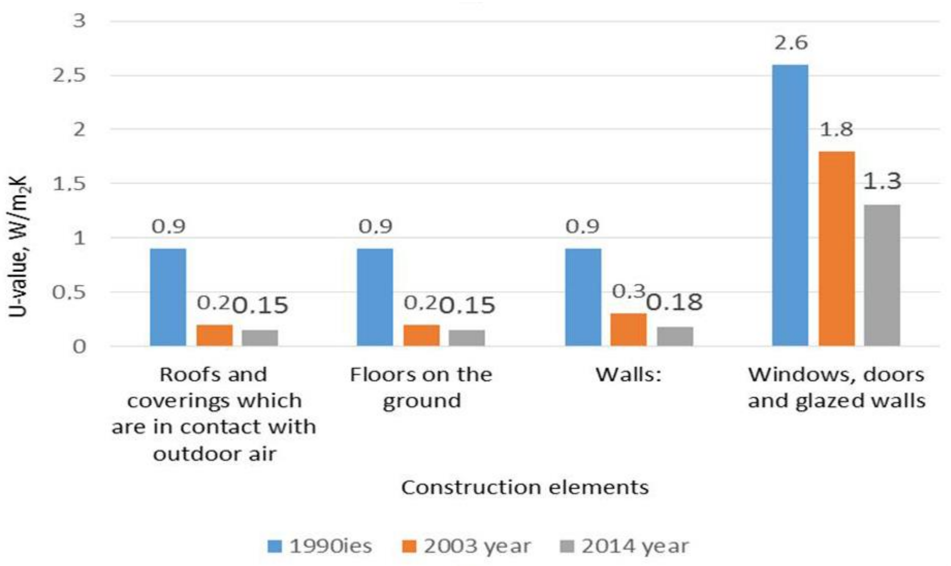


Figure 1. U-value for residential buildings in Latvia

Energy consumption of existing multi apartment buildings

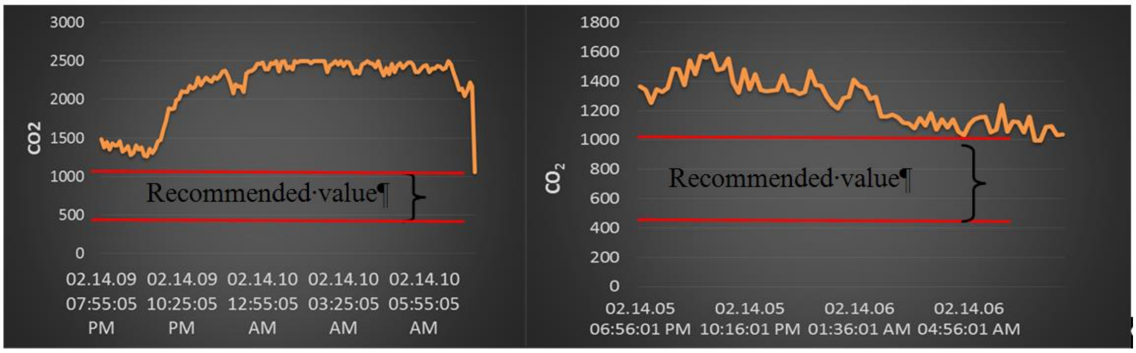
To evaluate the impact of renovation measurements of consumed energy for heating have been performed and comparison to the predicted ones has been made. The Table 3 shows how these results stack up.

Table 3. Comparison of heat consumption before renovation with theoretically predicted and measured heat consumption in Latvia

Objects	**Heat consumption**		
	Non-renovated	**After renovation**	
		Theoretical estimation	**Real measured**
Kindergarten	227kWh/m^2 (30.5 tCO_2)	121kWh/m^2 (17.3 tCO_2)	150kWh/m^2 (21.8 t/CO_2)
Kindergarten	245kWh/m^2 (89.3 $kgCO_2$)	117kWh/m^2 (58.3 tCO_2)	145kWh/m^2 (71.9 t/CO_2)
Residential building	150kWh/m^2 (89.3 $kgCO_2$)	78kWh/m^2 (54.5 t/CO_2)	75kWh/m^2 (44.6 t/CO_2)

As seen from the Table 3 there are some differences between predicted and measured energy consumptions and mostly the actual measured heat consumption is higher than predicted one. This can be explained by reason that the indoor temperature had risen after renovation. In most cases, this can be considered as a good thing because the indoor temperature before the renovation was too low and by increasing it the indoor climate quality is improved. However, if the temperature rise is unwanted the heating system needs to be rebalanced after the renovation or automation for heating boiler must be installed.

The research [5, 19] had shown unsatisfactory indoor air parameters in partly renovated and non-renovated buildings. The main reason for high level of CO_2 emission is lack of air exchange and absence of any ventilation systems. Figure 2 presents comparison of real measured CO_2 concentration under different ventilation scenarios in bedroom occupied by two adults.



a) without supply/exaust ventialtion   b) with supply/exaust ventialtion

Figure 2. presents comparison of real measured CO_2 concentration under different ventilation scenarios

As it can be seen form above-mentioned figure, the especial attention should be paid to proper design of ventilation systems.

According to the STEP-UP [http://stepupsmartcities.eu/] project data, since 2012, each building in City of Riga with a heat substation has been equipped with telemetering system enabling remote heat consumption measurements to be taken. Other data, such as cold and hot water as well as electricity, can be read in accordance with the client's needs. The project implementation was financed by the Riga utility company Riga Siltums through its own capital and loan mechanism. The upgraded meters introduction cost approximately 2.45 m Euro. It now takes less than three hours to take readings from more than 8,000 substations, saving staff time and ensuring greater data and billing accuracy. The new measures ensure any issues are more quickly resolved and risks identified promptly.

Nowadays energy performance of postwar construction is actual not only in former soviet countries [7, 15], but also in European countries [7, 8]. The new innovative technologies should be implemented in new construction as well as in retrofitting of existing buildings. Of the latest studies [4] have shown benefits of latent heat storage in Latvian climatic conditions. Application of latent thermal storage allows reduction of peak loads and wider application of solar energy. According to the study [13] data, optimization of heat consumption and peak loads allows significant saving in district heating systems. Thus overall negative environmental impact is minimizing.

Borodinecs A., Zemitis J., Sorokins J., Baranova D.V., Sovetnikov D.O. Renovation need for apartment buildings in Latvia. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 58–64. doi: 10.5862/MCE.68.6

Conclusions

There are approximately 38 933 multi apartment buildings in Latvia. Until February of year 2013 the total number of already renovated multi storey buildings in Latvia had reached 156 or only 0.4 %.

The heat consumption after applying thermal insulation during refurbishment process of buildings can be realistically reduced down to 70 kWh/m^2 in typical Latvian climate conditions. While nZEB approach requires reduction of thermal energy consumption up to 15–40 kWh/m^2 in Latvian climatic conditions.

The optimal U-values of walls after thermal insulations is 0.18–0.22 W/(m^2·K), while for roofs 0.13–0.15 W/(m^2·K).

Due to ventilation systems usually are not renovated, the IAQ measurements in renovated buildings have shown unsatisfactory situation with increased CO_2 concentration and high relative humidity.

The nZEB solution should include complex retrofitting measures as well as installation of energy storage, renewable energy sources and exhaust air heat recovery.

Acknowledgements

This study was supported and financed by European Regional Development Fund project “A New Concept for Sustainable and Nearly Zero-Energy Buildings” Nr. 1.1.1.1/16/A/007.

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doi: 10.5862/MCE.68.7

Building inside air temperature parametric study

Параметрический анализ внутренней температуры воздуха здания

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Key words: energy efficiency; modeling; heating rate; air exchange; inside air temperature; climatic data; regression

Ключевые слова: энергоэффективность; моделирование; уровень отопления; воздухообмен; внутренняя температура; климатические данные; регрессия

Abstract. Nowadays energy resources saving problem is extremely important, especially for heating in buildings. The aim of the paper is to simulate indoor air temperature depending on heating rate, solar heat gains, infiltration rate and outdoor air temperature. In order to get the desired result dynamic model of the room was created in EnergyPlus program, which is a widely used building energy simulation program. Based on the developed model and modified IWEC weather data the series of simulations were performed for inside air temperature calculation depending on internal and external factors changes. The analysis of individual and aggregate factors influence on inside air temperature change is performed. The multiple linear regression model structure is analysed and background of factors change over the past three days is chosen. Regression models for daily average inside air temperature dependence on each of the factors and all of them are created. Results verification is performed for prognosis values of temperature in comparison with simulation for December weather data from IWEC. Regression models can be used for complex analysis of problems connected with selecting heating rate, influence assessment of climatic conditions on indoor air temperature, qualitative and quantitative heating system regulation.

Аннотация. В настоящее время проблема экономии энергоресурсов очень актуальна, особенно с точки зрения потребления на отопление зданий. Целью работы является моделирование изменения внутренней температуры воздуха в зависимости от уровня отопления, солнечных теплопоступлений, инфильтрации и наружной температуры. Для достижения поставленной цели была разработана динамическая модель комнаты в программном продукте EnergyPlus, широко используемом для энергетического моделирования зданий. На основе математической модели и модификации погодных данных IWEC проведен ряд имитационных моделирований внутренней температуры воздуха в зависимости от изменения внутренних и внешних факторов. Рассмотрено индивидуальное и совместное влияние выбранных факторов на изменение температуры воздуха во времени. Проведен анализ и выбрана структура многофакторной линейной регрессии для определения влияния предыстории изменения факторов. Построены регрессионные зависимости внутренней температуры воздуха для каждого из факторов и регрессионная модель для совместного влияния факторов. Проведена верификация полученных результатов по внутренней температуре на базе регрессионного анализа в сравнении с данными имитационного моделирования для декабря с данных IWEC. Регрессионные зависимости могут быть использованы при комплексном подходе к решению задач, связанных с подбором уровня отопления, оценке влияния климатических факторов на внутреннюю температуру воздуха, качественным и количественным регулированием систем отопления.

Introduction

Anthropogenic climate change really entered the arena of a broad experts review. Impact assessment of various aspects of social life, including building energy consumption, indoor air quality, and overall building energy performance, on climate change is of great importance. Also, today the problem of energy resources saving is extremely important for Ukraine. According to the data obtained

Белоус И.Ю., Дешко В.И., Сухогуб И.О. Параметрический анализ внутренней температуры воздуха здания // Инженерно-строительный журнал. 2016. № 8(68). С. 65–75.

from [1] energy consumption for buildings operation is about 2.3 GJ/year, and this is more than 25 % in the energy balance of Ukraine. A large proportion of building energy consumption accounts for heating. Heating system qualitative adjustment depending on changes in internal and external parameters allows to improve comfortable indoor conditions and to achieve energy savings during heating period.

There are different methods that are used for building energy efficiency assessment. The research works of V.N. Bogoslovskij and Ju.A. Tabunschikov made a significant contribution to development of mathematical models for buildings energy performance system analysis, the implementation of which requires the creation/availability of special software platforms [2, 3].

The most simple and commonly used method to calculate energy consumption for heating is based on heating degree-days [4]. Fixed duration of heating period is needed for heat transfer losses and heat gains calculation.

However, this method can over evaluate the energy consumption for heating because of not taking into consideration building thermal inertia. Other method based on EN ISO 13790 [5] can use hourly (5R1C model) or monthly time periods for calculation in order to take into account building thermal mass. There are some modifications of simplified hourly model, for example 6R1C, that divide ventilation into controlled and uncontrolled (infiltration) parts and provide optional equations for different HVAC systems [6].

CFD software packages can be used to perform more detailed investigate heat and mass transfer processes in buildings in steady-state and transient modes [7]. It can be used to assess influence of external and internal factors on thermal state of the space, local ventilation characteristics, thermal comfort etc. Although, the calculation of unsteady-state heat and mass transfer processes in buildings using CFD packages can be quite a challenge.

One of the most convenient and precise way to investigate energy efficiency and thermal state of buildings is to use whole building energy simulation programs as EnergyPlus, DOE-2, eQuest, TRNSYS etc. [8]. Some researches compare real energy consumption with data obtained from different building simulation programs [9, 10], others compare different software in terms of results accuracy and convenience of use [11–13].

EnergyPlus is a widely used building energy simulation program that includes modules for zones thermal balance and HVAC equipment analysis [14]. EnergyPlus was created on basis of DOE-2, BLAST, which makes it attractive for use due to the accuracy of simulation results [15, 16], that were compared with actual building energy consumption [17–19].

It can be used for detailed simulation of convective and radiant heat transfer, infiltration and natural ventilation, solar and internal heat gains etc. EnergyPlus uses the Window 5 program for heat transfer calculation through windows and glazed doors [20] that considers layer by layer input of glazing system with different optical properties on front and back side of the glass, the angles of radiation incidence and reflection, heat balance iterative calculation for glass surface temperature determination, heat transfer through frame and dividers, the impact of internal and external shading devices etc. EnergyPlus considers one dimensional heat transfer through building envelope, therefore thermal bridges effect [21] is not calculated explicitly. In order to account for thermal bridges effect heat transfer coefficients for building envelope constructions can be modified. EnergyPlus is based on an integrated approach of heat and mass balance and technical building systems calculation that results in more accurate estimation of indoor air temperature. Some of the papers propose to use predetermined from dynamic simulation “normalized energy consumption coefficients” in combination with monthly energy bills in order to obtain the hourly distribution of energy consumption for typical buildings [22].

Using of dynamic modelling is complex and time consuming. That is why empirical modelling techniques using neural network [23], fuzzy logic [24, 25] and regression analysis are recently becoming widespread. Creating regression models are adequate alternative to complex building modelling and tool for heat consumption forecasting, ensuring adequate indoor comfort conditions. Regression models which allow analyzing and predicting the behaviour of various aspects of the building as an energy system can be based on actual data of energy consumption and factors that influence it [26–29]. For example, monitoring of indoor air temperature in the space allows building regression models for indoors temperature prediction based on external and internal factors [30]. Also regression based models can be used for analysis of heat consumption regulation efficiency including heat source (qualitative) and consumer (qualitative) [31–33]. But sometimes it is difficult to get the actual values of all influencing factors or it is not possible to assess a single influence of factors on indoor temperature. That is why other researchers use building simulation models to produce data for regression analysis [34–36].

Created regression models allow describing the indoor air temperature and energy consumption with sufficient accuracy. Also its usage is not so complex and time consuming as actual building simulation. But it has some limitations, it can be used only within the applied range of influencing factors, also models were created for climatic conditions in different countries.

The aim of the paper is to simulate indoor air temperature depending on heating rate, solar heat gains, infiltration rate and outdoor air temperature. In order to get the desired result following tasks were addressed: room model creation in EnergyPlus; investigation of different factors impact on the internal temperature; creation of multi-regression models to assess the individual and cumulative effect of selected factors.

Methods

Model description

Dynamic model of a room was created in EnergyPlus software for indoor air temperature investigation. Created model can be used for different objectives: calculation of heating and cooling load for design conditions under determined inside temperature; defining energy consumption for longer periods, for example, annual calculation; indoor air temperature calculation based on energy balance of the zone, including heat losses, heating rate, solar and internal heat gains. The last one can help to investigate the influence of building envelope thermal resistance, internal and external factors on temperature conditions inside the room for high-quality regulation of heating system. Level of solar heat gains can be adjusted by different types of shading devices and special glass coating [16].

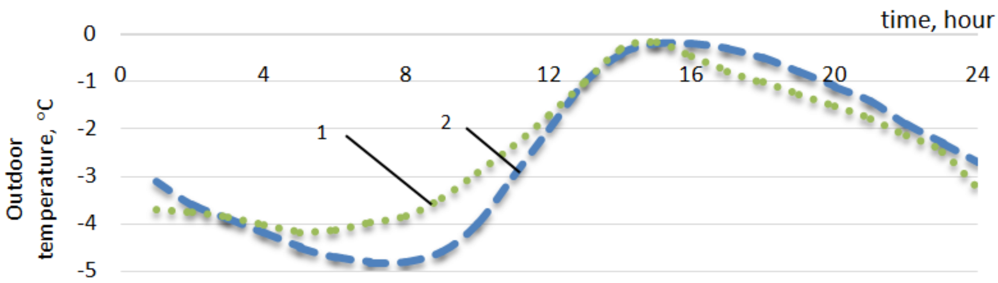
Mathematical model in EnergyPlus program takes into account diffuse and direct solar radiation (using direct normal radiation) for solar heat gains calculation through windows and opaque building elements.

The object of investigation is a room with one outside wall with window, tree interior walls, interior ceiling and floor. Room floor and ceiling size is 5.5 × 6.1 m, floor-to-ceiling height is 3.2 m. The dimensions of exterior wall are 5.5 × 3.2 m, exterior window is 5 × 2.5 m. The design of the building meets the requirements of the building construction of 1970s that accounts for 80–90 % of existing buildings in Ukraine. Regardless of the current normative value of thermal resistance 3.3 (m^2·K)/W the existing outer wall has the thermal resistance R = 1 (m^2·K)/W. The outer window is double glazed system with wooden frame. It has no interior or exterior shading devices. Interior walls have and are built with half-brick (δ = 0.125 m). Ceiling and floor is reinforced concrete slab (δ = 0.2 m). Ventilation is natural. Model input parameters are hourly climatic data from IWEC file (International Weather for Energy Calculation), that include dry-bulb temperature, relative humidity, atmospheric pressure, wind speed and direction, direct and diffuse solar radiation etc. Also, heating level, infiltration rate, floor number and building orientation can be changed.

Conditions of model functioning

Inside air temperature is dependent on number of factors. EnergyPlus takes into account the following ones: outside air temperature, direct and diffuse solar radiation, wind pressure, wind speed and direction, humidity, internal heat gains from people, electric appliances and lightning, heating rate, air exchange rate etc Outside air temperature, solar heat gains, infiltration rate and heating rate were chosen as the most influencing ones for the analysis of existing buildings based on the previous research data. The main objective of dynamic modelling is to investigate the change of indoor air temperature due to disturbances of each influencing factors and their consistency in the given range. Ten minute time intervals were used in heat balance calculation in EnergyPlus. After the stabilisation of indoor air temperature profile one of the factors value was changed and its influence on indoor air temperature conditions was analyzed.

Weather conditions of typical December day were selected as base from IWEC file for Kiev, Ukraine. Temperature conditions of the selected day are close to the climatic data from [37] (fig. 1). Daily fluctuations in outside air temperature (t_o) in December for Kiev are in the range of 0 ... –5˚C.



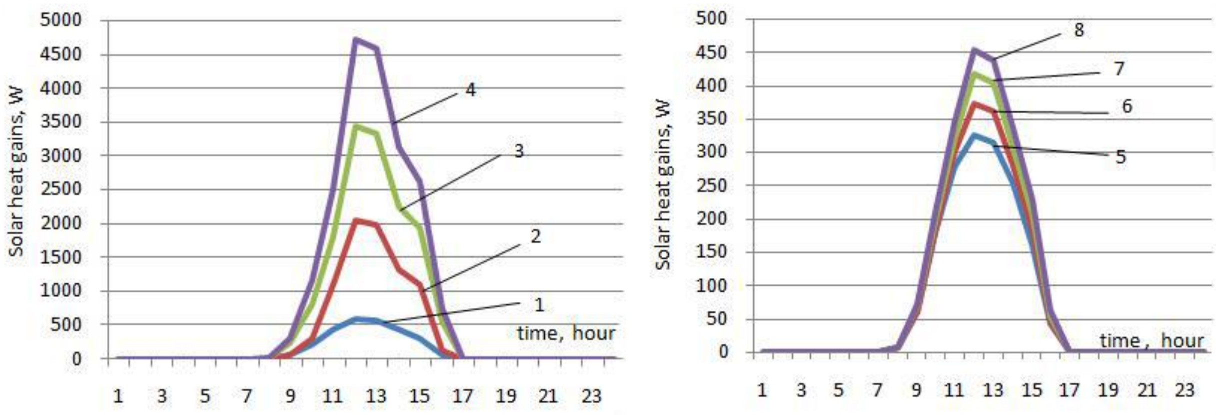
1 – data from IWEC file, 2 – data from [31]

Figure 1 – Daily changes in outdoor air temperature for December typical day

Peak value of global solar radiation on horizontal surface is 115 W/m^2 for cloudy December day from IWEC file data. According to climatic data from [37] its average daily value is 22 W/m^2. Selected base values for diffuse and direct normal radiation provide the magnitude of solar heat gains through exterior window with southern and northern cardinal direction in the range 0…600 W and 0…325 W respectively (fig. 2). Wind speed was set to 2.7 m/s with prevailing western direction [38]. For the base calculation air changes per hour was set to 1 hour^{-1}. The heating rates for base external conditions were selected taking into account the room orientation (southern or northern) and were 1300 and 1365 W respectively, that accounts for 62 and 65 % of design heating rate (2100 W). Given base input values provide average daily value for indoor air temperature t_{in} = 18 ºC after stabilisation.

Base climatic data were introduced in modified IWEC file. Initial calculations show that daily fluctuation of indoor air temperatures become stable on the 20th day provided that daily average base parameters are constant. Using the modifications of IWEC weather file influencing factors are changed alternately. Disturbances of external temperature daily fluctuations correspond to the daily average change value in the range Δt_{out} = [3…+3]ºC. Amplitude of fluctuations remained the same as in Figure 1. For the overall heating period in Kiev maximum between-day outside air temperature fluctuations is 6–10 °C. Average between-day temperature fluctuations are 3–4 °C based on weather data from IWEC file.

Although the model uses solar radiation data from IWEC file, that include diffuse horizontal and direct normal radiation, the resulting solar heat gains through the window are taken for the analysis of solar radiation impact on indoor air temperature. Disturbances of solar heat gains (fig. 2) were set by changing the daily fluctuations of direct solar radiation, thus taking into account room orientation. EnergyPlus calculates the value of direct solar heat gains through direct normal radiation value. The maximum daily fluctuations of direct normal radiation were changed in the range of 0...600 W/m^2 in increments of 200 W/m^2, leaving the same daily behaviour characteristics. This range corresponds to heating period conditions. Fluctuations rate of daily diffuse solar radiation is in the range of 0...100 W/m^2 and is not changed. Solar activity disturbances were simulated for the duration of one day and three days.



a) b)

Figure 2. Zone solar heat gains through the window for the southern (a) and northern (b) side of the building: Daily average solar heat gains: 1 –119 W (base), 2 – 344 W, 3 – 608 W, 4 – 827 W, 5– 67 W (base), 6 – 73 W, 7 – 81 W, 8 – 87 W

The disturbances range of infiltration (air changes per hour) for the zone was 0.5 ... 1.5 hour^{-1}. This range is chosen taking into account the influence of internal and external air temperature difference, number of storeys, wind speed and direction [39]. Heating rate disturbances values are set to 45–85 % from design value.

Results and discussions

The influence of influencing factors on the indoor air temperature

The zone with considered thermal properties of building enclosures comes to stationary mode within an average period of 20 days provided that external and internal parameters are constant (fig. 3). That is why the disturbance of each influencing factor was set on the 20th day and changes in internal temperature behaviour were investigated. It is difficult to determine the weight/influence of each of the selected factors under the combined influence of external factors on the internal temperature and predict the behaviour of a building system with other combinations of disturbances. In order to determine the individual impact of factors each of them is examined in turn.

Daily fluctuations of southern oriented room inside air temperature for 1-day and 3-day disturbances of solar radiation are shown in Figure 3. Daily maximum temperature is increased by 2–6 °C, depending on the level of disturbance. For the room with outside window oriented to the north daily fluctuations of the internal temperature barely changed. After 1-day solar radiation disturbance the considerable remaining effect lasts for 5–6 days, for 3-day disturbance it can last for 10 days approximately.

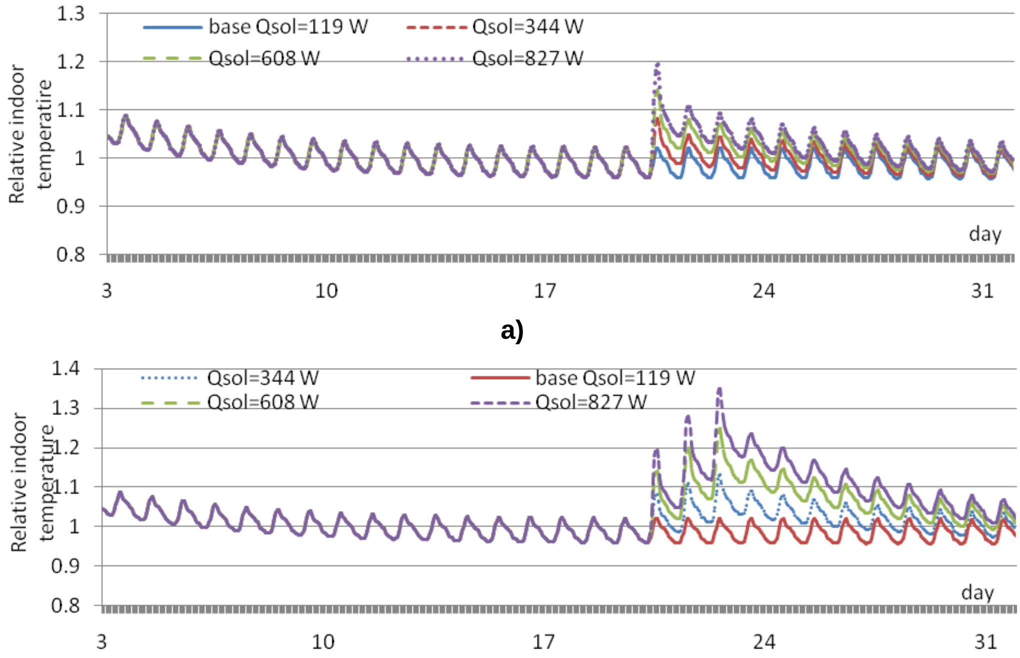


Figure 3. Daily fluctuations of inside air temperature for the room oriented to the south for various disturbances of solar heat gains for the duration of one day (a) and three days (b)

Taking into account the convenience to analyze the impact of factors disturbances in daily time intervals derived results were averaged for each day. Modelling results for outside air temperature, infiltration and heating rate disturbances impact on daily average inside air temperature are given in Figures 4–5. As opposed to solar radiation the values of the factors do not return to the base values. The disturbance impact on the indoor temperature depends on its value and has a remaining effect up to 10 days.

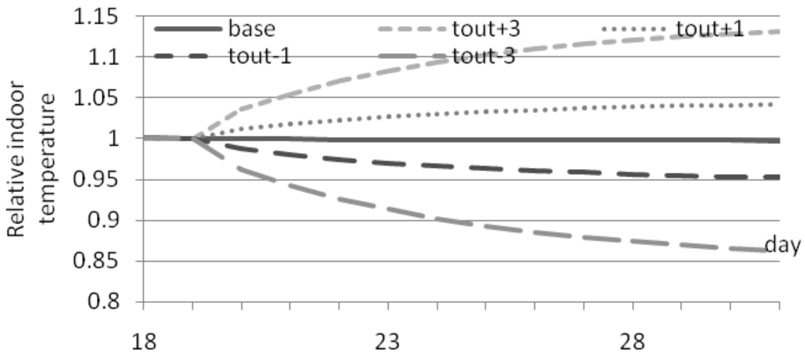


Figure 4. Daily average inside air temperature for different outside air temperature disturbances

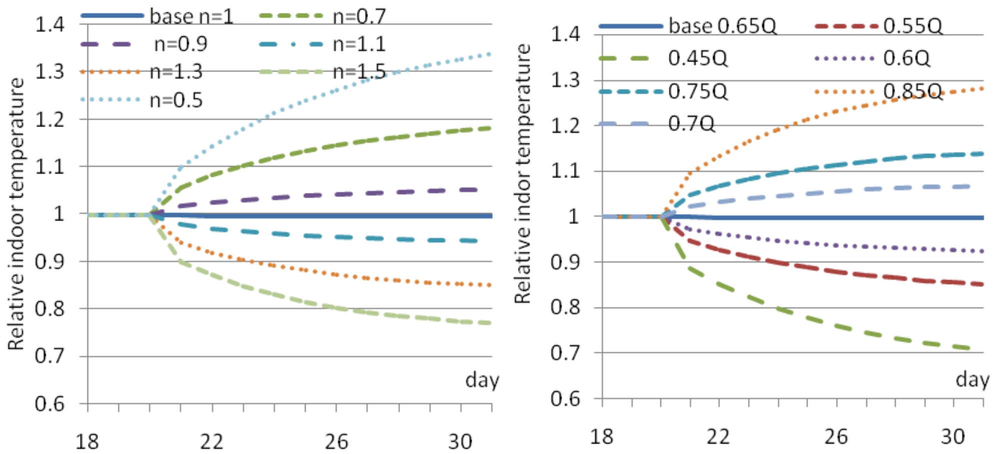


Figure 5. Daily average inside air temperature for different infiltration (a) and heating rate (b) disturbances

It should be noted that daily average inside air temperature curves for symmetric disturbances of infiltration rate do not behave symmetrically with respect to the baseline. Analysis of simulation results shows that prehistory of influencing factors should be taken into consideration for correct estimation of indoor air temperature.

Creation of regression model

Linear multiple regression model built on the base of least square technique is used to predict daily average inside air temperature for different values of influencing factors. Non linear time effect is included by using difference of factors values for different days. Values normalization for regression model was performed for given ranges of factors: outside air temperature Δt_{out} = 13 °C, inside air temperature Δt_{in} = 12 °C, infiltration rate Δn = 1.5 hour^{-1}, heating rate ΔQ = 900 W, solar heat gains ΔQ_{sol} = 1000 W.

Prehistory of factors analysis is carried out for outside air temperature change, from 1 to 5 prehistory days analysis is given. Difference of outside air temperature values for adjacent days is used in the regression models. The equation that includes 5-day history of the factor gives the most precise results of indoor air temperature comparing to dynamic simulation data. If the number of prehistory days is decreased to one, regression results greatly deviates from the curve of daily average inside air temperature from simulation modelling (1–2 ºC). That is why the regression model that includes 3-day prehistory of the factor is considered in the paper, which provides sufficient accuracy of inside air temperature prognosis. Figure 6 gives prognostic values of temperature inside the zone depending on disturbances of outside air temperature for December from IWEC using 3-day prehistory regression model. As the model can be used for several days' temperature prediction, 1-day and 3-day prognosis values are given versus modelling results.

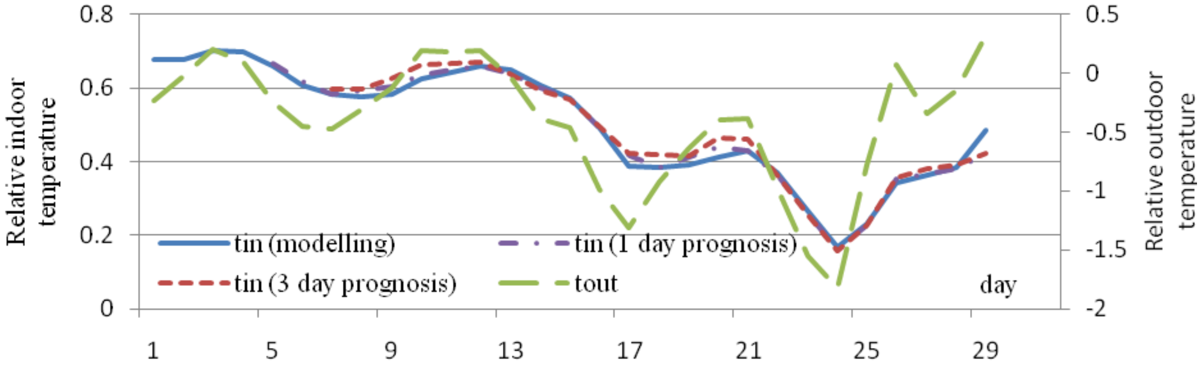


Figure 6. Prognostic values of inside air temperature depending on disturbances of outside air temperature

Regression models that include the background of factors change over the past three days and inside air temperature for the previous day can be written as follows:

– for outside air temperatures

$$t_{\text{in.i}} = -0.03242 + 1.05734 t_{\text{in.i}-1} + 0.2519(t_{\text{out.i}} - t_{\text{out.i}-1}) + 0.11633(t_{\text{out.i}-1} - t_{\text{out.i}-2}) + \\ +0.08283(t_{\text{out.i}-2} - t_{\text{out.i}-3}),$$
$$R^2_{\text{adj}} = 0.99854,$$

– for solar heat gains

$$t_{\text{in.i}} = -0.04384 + 1.07479 t_{\text{in.i}-1} + 0.12189(Q_{\text{sol.i}} - Q_{\text{sol.i}-1}) + 0.14401(Q_{\text{sol.i}-1} - Q_{\text{sol.i}-2}) + \\ +0.0911(Q_{\text{sol.i}-2} - Q_{\text{sol.i}-3}),$$
$$R^2_{\text{adj}} = 0.96085,$$

– for infiltration rate

$$t_{\text{in.i}} = -0.02657 + 1.05784 t_{\text{in.i}-1} - 0.41018(n_{\text{i}} - n_{\text{i}-1}) - 0.16468(n_{\text{i}-1} - n_{\text{i}-2}) - \\ -0.10165(n_{\text{i}-2} - n_{\text{i}-3}),$$
$$R^2_{\text{adj}} = 0.99679,$$

– for heating rate

$$t_{\text{in.i}} = -0.05587 + 1.106 t_{\text{in.i}-1} + 0.34094(Q_{\text{i}} - Q_{\text{i}-1}) + 0.0854(Q_{\text{i}-1} - Q_{\text{i}-2}) + \\ +0.04943(Q_{\text{i}-2} - Q_{\text{i}-3}),$$
$$R^2_{\text{adj}} = 0.99912,$$

where i – day number; t_{in} – daily average inside air temperature; t_{out} – daily average outside air temperature; Q_{sol} – daily average solar heat gains; Q – heating rate; n – infiltration rate.

The processing of calculation results for individual factors influence on daily average inside air temperature using multiple linear regression models provides adjusted coefficient of determination value R^2_{adj} above 0.99, with the exception of solar heat gains influence, where R^2_{adj} is equal to 0.96.

The overall regression model that takes into account all the influencing factors can be written as follows:

$$t_{\text{in.i}} = -0.03123 + 1.05865 t_{\text{in.i}-1} + 0.25119(t_{\text{out.i}} - t_{\text{out.i}-1}) + 0.11633(t_{\text{out.i}-1} - t_{\text{out.i}-2}) + \\ +0.08283(t_{\text{out.i}-2} - t_{\text{out.i}-3}) - 0.41018(n_{\text{i}} - n_{\text{i}-1}) - 0.16435(n_{\text{i}-1} - n_{\text{i}-2}) - 0.10117(n_{\text{i}-2} - n_{\text{i}-3}) + \\ +0.11864(Q_{\text{sol.i}} - Q_{\text{sol.i}-1}) + 0.14158(Q_{\text{sol.i}-1} - Q_{\text{sol.i}-2}) + 0.0904(Q_{\text{sol.i}-2} - Q_{\text{sol.i}-3}) + \\ +0.34094(Q_{\text{i}} - Q_{\text{i}-1}) + 0.10154(Q_{\text{i}-1} - Q_{\text{i}-2}) + 0.07133(Q_{\text{i}-2} - Q_{\text{i}-3}),$$

The processing of general calculation results for individual factors influence using the latter equation provides R^2_{adj} value equal to 0.994. Other characteristics for assessing the adequacy of regression model are the average approximation error $\bar{\mathcal{E}} = 0{,}45\%$ and standard error $\sigma_0 = 0.013$.

The comparison of prognosis values of inside air temperature using the last of the proposed regression model with modelling results for December weather data from IWEC is given in Figure 7. The proposed regression models describe the change in average daily internal air temperature with standard deviation equal to 0.6 °C.

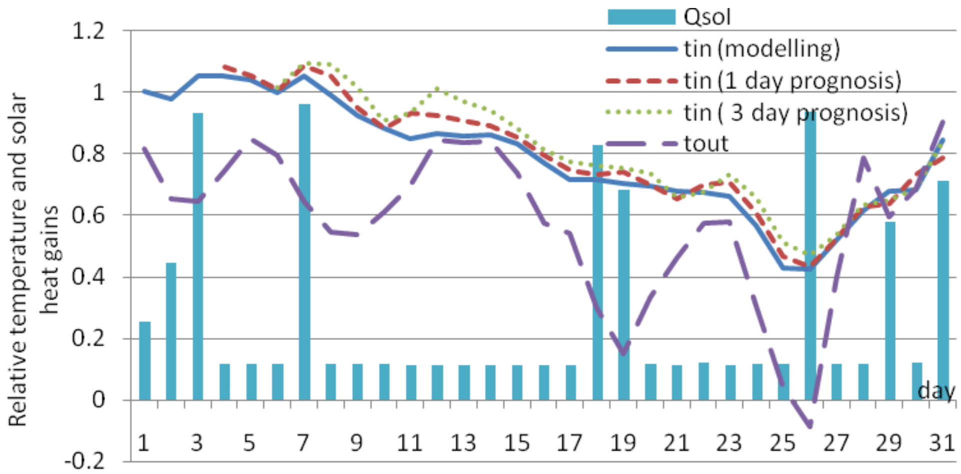


Figure 7. Prognosis values of inside air temperature for December weather data

The majority of existing heating system control methods is based on inside air temperature regulation; therefore it was used as desired parameter for regression models. At the same time EnergyPlus calculates operative temperature (that combines inside air temperature and mean radiant temperature). Further development of proposed regression models based on EnergyPlus simulation results can include investigation of operative temperature depending on influencing factors. This approach provides the analysis of internal and external factors influence on human thermal comfort [40].

Conclusions

Developed dynamic model based on EnergyPlus and modified IWEC weather data are used for the research of individual and aggregate factors influence on inside air temperature change. The regression model structure is analysed and background of factors change over the past three days is chosen. The possibility of using the proposed regression model for several day prognoses of daily average inside air temperature is considered.

Such regression models can be used for the following tasks:

1. selection and prognosis of heating rate in the room at a constant internal temperature and change of external factors;
2. assessment of internal temperature change at fixed and variable values of heating rate and changing external conditions;
3. assessment of internal temperature change at values of heating rate depending on outside air temperature taking into account change of external factors.

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doi: 10.5862/MCE.68.8

Self-compacting concrete with limestone powder for transport infrastructure

Самоуплотняющийся бетон с карбонатным наполнителем для объектов транспортной инфраструктуры

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Key words: self-compacting concrete; limestone powder; energy efficiency; strength; buildings; construction; civil engineering; water permeability; frost resistance

Ключевые слова: самоуплотняющийся бетон; карбонатный наполнитель; энергосбережение; гражданское строительство; конструкции; прочность; водонепроницаемость; морозостойкость

Abstract. At the beginning of XXI century in civil engineering and buildings of transport infrastructure, such as tunnels, elements of bridges, viaducts and roads, it is more expedient to use conventionally vibrated concretes which have almost universally replaced prefabricated constructions. However, in objects with high congested reinforcement or in cases where vibration is impossible it is more preferable to apply self-compacting concrete (SSC) mixtures. SCC possesses the ability to take form shape without any mechanical aid. The most important requirement for SCC is high flowability without the segregation of aggregate during placement. Despite the low water-cement ratio of the fresh self-compacting concrete mixture the bleeding is still possible. That is why fillers such as natural pozzolana, calcined clay (metakaolin), silica fume, fly-ash, slag, and quarry dusts should be used. Furthermore, mineral admixtures can improve energy efficiency and particle packing, decrease cost and permeability of self-compacting concrete. In this study, the properties of SCC with limestone powder as partial replacement of Portland cement was established by applying mathematical experiment planning method. The obtained SCC gave high early compressive strength within 3 days in the range of 41.3 MPa while its 28 day strength ranged of 69.0 MPa. The result of this study indicated the possibility of adding limestone powder in SCC with optimum percentage content around 38 %. The researched SCC had density of hardened and fresh concrete mix in the ranges of 2438 kg/m3 and 2452 kg/m3 respectively. The investigated SCC concrete with limestone powder showed high rate of water permeability in the range of 1.6 MPa (W16) and high frost resistance in the ranges of F2400. It can be explained by additive's high water retention capacity and increase of hydration degree and, as a consequence, decrease of capillary porosity. That is why the developed SCC with limestone powder has high compressive strength and excellent durability performance.

Аннотация. На объектах гражданского строительства и транспортной инфраструктуры в конструкциях, имеющих высокий коэффициент армирования, и в случаях, когда вибрирование бетонных смесей осуществить не представляется возможным, необходимо применение эффективных самоуплотняющихся бетонных смесей, которые получили широкое распространение в последние десятилетия в мировой практике. В работе представлены результате экспериментальных исследований при разработке состава самоуплотняющегося бетона для объектов транспортной инфраструктуры с использованием наполнителей на основе отходов дробления карбонатных пород. Для оптимизации состава применялся трехфакторный метод математического планирования эксперимента, композиционный план на кубе типа B3, обеспечивающий максимальную прочность при достижении требуемых технологических показателей. Установлено, что введение эффективного разжижжителя в виде гиперпластификатора, значительно снижает водосодержание бетонной смеси, что предотвращает расслаиваемость самоуплотняющегося бетона и повышает эксплуатационные свойства: прочность, морозостойкость, водонепроницаемость. Экспериментально установлено, что увеличение содержания карбонатного наполнителя ведёт к повышению прочности только до определённого предела, оптимальная дозировка которого, соответствующая максимальной

Larsen L.O., Naruts V.V. Self-compacting concrete with limestone powder for transport infrastructure. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 76–85. doi: 10.5862/MCE.68.8

прочности, составляет 0.38 от массы цемента. Карбонатный микронаполнитель, обладая высокой водоудерживающей способностью, повышает степень гидратации цемента, способствует уменьшению капиллярной и общей пористости, тем самым влияя на показатели прочности. Получен самоуплотняющийся бетон со средней плотностью 2438 кг/м3, прочностью на сжатие 69 МПа, морозостойкостью F2400 и водонепроницаемостью W16.

Introduction

At the beginning of XXI century in constructions, such as tunnels, elements of bridges, viaducts and roads conventionally vibrated concretes are widely used. However, it is more preferable to apply self-compacting concrete mixtures in structures with high density reinforcement or in cases where vibration is impossible [1]. Due to high rate of flowability self-compacting concrete takes form shape and passes through the bars without any vibration. Self-compacting concrete has several advantages such as technological benefits, environmental impact and energy efficiency [2].

The difference in concrete mix design between SCC and conventionally vibrated concrete is in lower coarse aggregate content, increased paste content, low water/powder ratio, increased superplasticiser [3]. The required level of flowability (slump more than 600 mm) can be achieved by adding polycarboxylate-based admixtures with maintaining of technological properties such as workability retention at the period of setting time into the formwork [4, 5]. Despite low water-cement ratio bleeding of the mix is still possible.

The high cost of SCC resulted from the high cement content is the main factor impeding the widespread of SCC use. Since cement is the most expensive component of concrete, its reducing content is an economical solution. The cost of SCC can be decreased incorporating various supplementary cementitious materials such as natural pozzolana [6], calcined clay (metakaolin) [7], silica fume, fly-ash [8], slag [9] and quarry dusts [10]. The mineral admixtures can improve particle packing and decrease the permeability of concrete. Therefore, the durability of concrete is also increased.

Besides the economical benefits, the use of recycled waste materials in concrete could reduce environmental pollution and carbon dioxide emission. Large volumes of these powders are accumulated and it is a big problem to propose utilization of these by-products from the aspects of disposal and health hazards [11].

In addition supplementary cementitious materials do not only decrease the cost of self-compacting concrete [12], but also improve flowability [13] and durability [14], reduce the heat of hydration in massive structures [15], increase early strength and control bleeding [16].

Calcium carbonate based mineral fillers are widely used and can give excellent rheological properties and a good finish. Limestone powder is a by-product collected from the quarrying process of carbonate rocks. In Russia, 2014, more than 300 million tons of natural limestone were extracted and recycled to produce 209 million tons of lime coarse aggregate and 10 million tons of lime binders [17, 18]. The main component of limestone powder is calcium carbonate. It does not possess pozzolanic activity [19], but its use in SCC improves the deformability and viscosity, as well as reduction porosity [20]. Partial replacement of cement by limestone filler brings the enhancement in fluidity and a reduction of the yield stress [21].

The amount of limestone powder in cementitious materials can vary from 10 to 50 % [22]. Due to positive influence on the properties of SCC and economic benefits the limestone powder is a major component of many SCC mixtures [23]. Some research has been conducted regarding the properties of limestone powder in self-compacting concrete in recent years. However, most of the previous studies are limited or contain compositions with different quantity of the filler. The aim of this study is to establish the optimum quantity of limestone powder in SCC and its influence on technological and performance properties.

Materials, methods and mixture proportioning

Cement

The cement used in this study was Ordinary Portland Cement type CEM I 42.5 N Holcim Rus in accordance with [24]. Mineral content was: C_3A = 7.2 %, C_3S = 60.8 %, C_2S = 13.7 %, C_4AF = 10.0 % with specific surface area equal to 3600 cm^2/g. Chemical composition is presented in Table 1.

Table 1. Chemical composition of CEM 42.5 N

Component	Percentage	Component	Percentage
SiO_2	18.6	TiO_2	0.3
Al_2O_3	4.5	P_2O_5	0.1
CaO	63.6	SO_3	3.1
Fe_2O_3	3.1	Na_2O	0.2
MgO	3.2	K_2O	0.6

Mineral filler

The limestone powder was sourced from limestone quarry Saltykovskoe field, grinded in laboratory mill to a specific surface area equal to 3500 cm^2/g. Chemical composition of limestone powder is presented in Table 2.

Table 2. Chemical composition of limestone powder

Component	Percentage, %					
Limestone powder	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Loss on ignition
	0.79	0.45	0.72	54.94	0.48	42.62

Aggregates

Crushed granite with a maximum size of 20 mm according to [25], specific gravity of 2.68 kg/m^3 and water absorption of 0.2 % according to [26] was used as coarse aggregate. Quartz sand was used as fine aggregate with specific gravity equal to 2.63 kg/m^3 with the fineness modulus of 1.2. The particle size distributions of both sand and crushed granite, obtained by sieving, are shown in Figures 1 and 2.

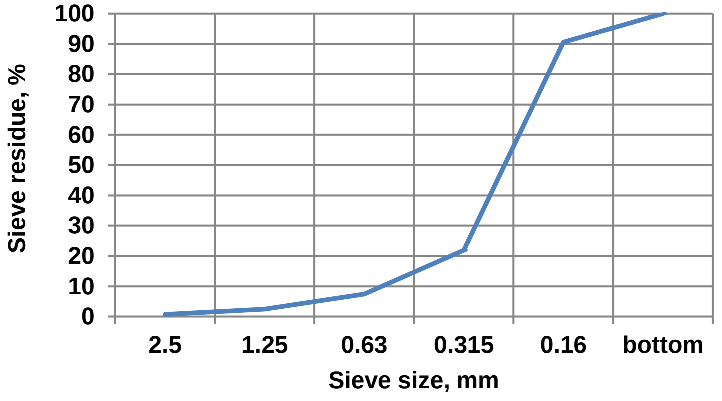

Fig. 1. Grading of fine aggregate

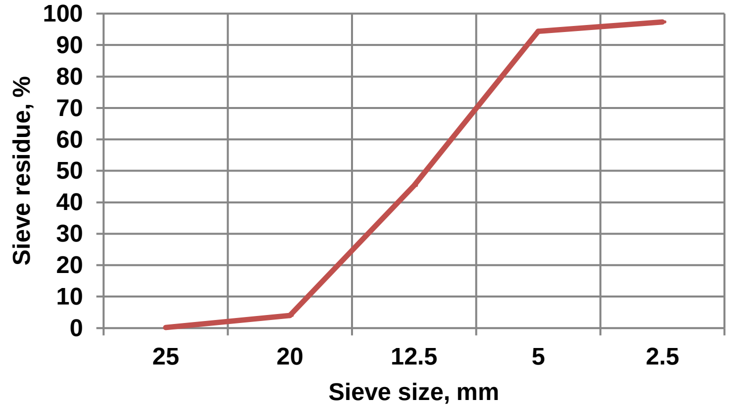

Fig. 2. Grading of coarse aggregate

Chemical admixture

To adjust the workability of concrete mixture, maintain its dispersing effect during the time, required for transport and application, a superplasticizer based on polycarboxylate ethers Sika ViscoCrete 5-800 was used in accordance with [27, 28].

Evaluation of self-compactability

At the beginning of the experiment preliminary composition of self-compacting concrete with the following characteristics presented in Table 3 was developed. It was experimentally determined that the dosage of superplasticizer using slump-flow test on the paste [29] until the rheological parameters attained satisfactory level (660–750 mm). Necessary correlation between limestone powder, coarse aggregate and fine aggregate is based on requirements of self-compactability [30] and terms of concrete mixtures pumpability [31].

Trial batches of SCC with simultaneous adjustment were produced. The weights of constituent materials for producing one cubic meter of SCC mixtures, calculated using the absolute volume method.

Table 3. Preliminary compositions of the mixture

Material	**Unit mass (kg/m^3)**
CEM I 42.5 N	480
Limestone powder	190
Quartz sand	720
Crushed granite	765
Water	170
PCE SP Sika ViscoCrete 5-800	5.8

Mathematical planning method

The obtained SCC composition was corrected by using three-factor mathematical planning method. A compositional plan for a B_3-type cube was adopted for the implementation of the experiment. The factors of variation were: quantity of Portland Cement in kg/m^3; quantity of limestone powder in % by weight of Portland Cement; quantity of chemical admixture Sika ViscoCrete 5-800 in % by weight of Portland Cement. Other parameters remained unchanged. The zero level of variation was adopted for the preliminary composition.

Evaluation of hardened properties

The cube samples 100 x 100 x 100 mm were cased in accordance with [32, 33, 34] from each composition with no compaction. Demolding of the cubes was carried out 24 hours after casting. The cubes were placed in a 20 °C water curing tank until tests. The compressive strength of each cube was measured according to [35] at the age of 28 days.

Frost resistance and water permeability

Frost resistance was determined in accordance with [36] by third accelerated method (freezing and thawing in 5 % aqueous solution of NaCl, temperature of freezing was -50 °C) on cube samples 100 × 100 × 100 mm at the age of 28 days by placing samples in a 20 °C water curing tank. Water permeability was determined by "wet spot" method following [37] at the age of 28 days.

Results and Discussion

Optimization of the compressive strength of SCC

The levels of variation factors are shown in Table 4. The results of the compressive strength at 28 days are shown in Table 5.

Table 4. Levels and intervals varying factors

Factor			**Levels varying factors**			**Intervals varying factors**
Parameter	Description					
	Natural	Code	+1	0	-1	
Quantity of CEM I 42.5 N, kg/m^3	X_1	x_1	570	480	390	90
Quantity of Limestone powder, mass proportion of PC	X_2	x_2	0.5	0.4	0.3	0.1
Quantity of PCE SP Sika ViscoCrete 5-800, % of PC	X_3	x_3	1.4	1.2	1	1

Table 5. Matrix of the system response

No	**CEM I 42.5 N, kg/m^3**	**Limestone powder, in proportion of PC**	**PCE SP Sika ViscoCrete 5-800, in % of PC**	**Coded factor**			**Parameter of optimization**
				x_1	**x_2**	**x_3**	**Compressive strength in age of 28 days (MPa)**
1	2	3	4	5	6	7	8
1	390	0.3	1	-1	-1	-1	47.6
2	570	0.3	1	1	-1	-1	61.3
3	390	0.5	1	-1	1	-1	50.2
4	570	0.5	1	1	1	-1	67.7
5	390	0.3	1.4	-1	-1	1	44.3
6	570	0.3	1.4	1	-1	1	52.2
7	390	0.5	1.4	-1	1	1	49.9
8	570	0.5	1.4	1	1	1	68.0
9	390	0.4	1.2	-1	0	0	53.4
10	570	0.4	1.2	1	0	0	65.3
11	480	0.3	1.2	0	-1	0	47.7
12	480	0.5	1.2	0	1	0	49.6
13	480	0.4	1	0	0	-1	48.6
14	480	0.4	1.4	0	0	1	54.1

The number of experiments was 14, the number of repeated experiments was 3. The preparation of the concrete mixtures was performed in a laboratory mixer. The final mixing time after dosage of all materials was 90 seconds.

The final purpose of the data processing was to obtain the equation of regression by the number of defined characteristics with significant coefficients for the selected variables:

$$y = 52.06 + 6.98x_1 + 3.32x_2 + 7.3x_1^2 - 3.4x_2^2 + 0.93x_1x_2 + 0.83x_2x_3 \quad (1)$$

The analysis of regression equations was carried by a mathematical method. Graphic dependences are presented in Figures 3 and 4.

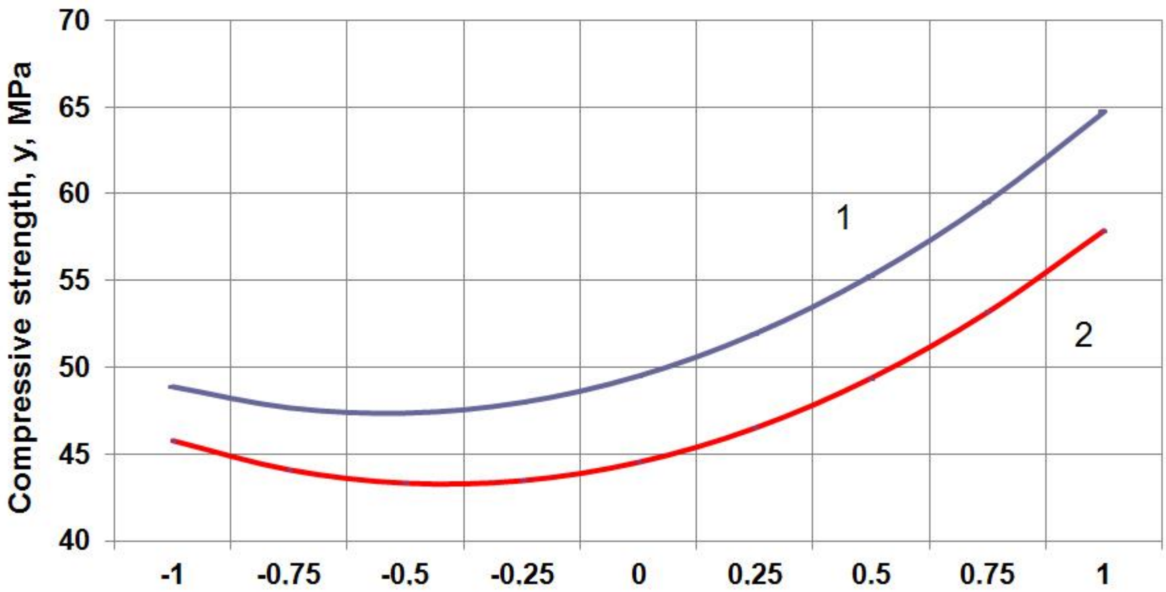

Figure 3. Dependency graphs of y = f (CEM I 42.5 N):
1 – dependency graph of y = f (CEM I 42.5 N) if x_2 = 1, x_3 = 1;
2 – dependency graph of y = f (CEM I 42.5 N) if x_2 = -1, x_3 =1

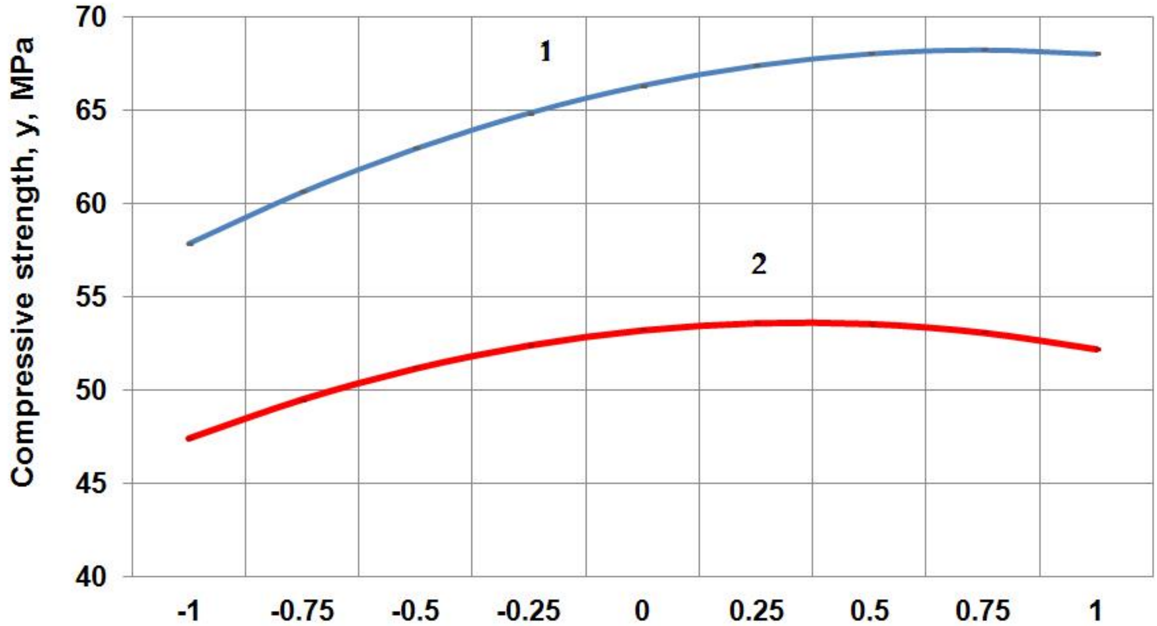

Figure 4. Dependency graphs of y = f (limestone powder):
1 – dependency graph of y = f (limestone powder) if x_1 = 1, x_3 = 1;
2 – dependency graph of y = f (limestone powder) if x_1 = -1, x_3 = 1

The composition with the highest compressive strength and optimum dosages of variable components was selected. The consumption of materials for one cubic meter based on the equation of regression (1) is presented in Table 6.

Table 6. Content of concrete mix by using mathematical planning method

Weights of the materials for one cubic meter of the concrete mixture (kg)						Estimated density (kg/m³)	Volume of aggregates	Estimated compressive strength (MPa)
CEM I 42.5 N	Limestone powder	Quartz sand	Crushed granite	PCE SP	Water			
570	217	720	765	8	190	2462	0.56	68.24

Table 7. Properties of fresh concrete mixtures and hardened concrete

Density (kg/m³)	Slump flow (mm)	t_{500} (s)	Density of hardened concrete (kg/m³)	Compressive strength (MPa)				Deviation from calculated strength, %
				3	7	14	28	
2452	690	9	2438	41.3	56.5	59.3	69.0	+1.11

As it seen from the Table 6 and 7 the content of limestone powder in optimal SCC was 38% by weight of Portland cement.

Frost resistance and water permeability

Table 8. Frost resistance and water permeability of self-compacting concrete

Testing method	The number of cycles of freezing/ thawing without failure and weight loss	Grade of freezing/ thawing	Sample size of cylinders (mm)	Water permeability (MPa)	Grade of water permeabilit y
Third rapid	55	F_2 400	d=150 mm h = 150 mm	1.6	W16

Conclusion

The test results showed possibility of using limestone powder in SCC. The results demonstrate positive influence of limestone powder on technological and performance properties. The obtained composition was optimized by mathematical planning method. It was determined that the optimal dosage of limestone powder in the developed SCC is 38 % to achieve technological requirements (690 mm of slump flow) with cement consumption equal to 570 kg/m³. It was established that the adding of limestone powder in amount of 38 % together with the superplasticizer causes increasement of compressive strength in 3, 7, 14 and 28-day in the range of 41.3, 56.5, 59.3 and 69.0 MPa respectively that correlates with compressive strength of existing SCC with other fillers [38]. The introduction of limestone powder provides high density of concrete (2438 kg/m³) that exceed existing results [39] and could enhance corrosion resistance and high durability. The developed SCC demonstrated 55 cycles of freezing/thawing, low rate of water permeability in the range of 1.6 MPa that can be explained by high water retention capacity on increase of the hydration degree by creating a high dense homogenous structure of the concrete.

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doi: 10.5862/MCE.68.9

The elementary mathematical model of sustainable enclosing structure

Простая модель теплоустойчивой ограждающей конструкции

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Key words: buildings; construction; civil engineering; energy efficiency; temperature; humidity conditions; the accumulation of heat; wall enclosure; problem of Cauchy

Ключевые слова: здания; строительство; гражданское строительство; энергоэффективность; температура; влажность; накопление тепла; ограждающие конструкции; задача Коши

Abstract. Energy efficiency building envelopes (walls, floors, facades) should meet the requirements of regulatory documents. The main attention is paid to structural and technological activities aimed at increasing the thermal resistance of protections. Estimates of the thermal stability of the wall are required for realization of high thermal resistance of the wall structure. The object of study is a simple model of the building envelope. It has been shown that the increased thermal conductivity, thermal resistance does not always provide the steady-state temperature faces the wall. Research method is based on the analysis of the properties of the Cauchy problem. In this article it is found out the connection between the active (thermal resistance) and reactive (accumulation) resistance enclosure on the model of one-dimensional wall.

Аннотация. Энергоэффективность ограждающих конструкций (стен, перекрытий, фасадов) должна соответствовать требованиям нормативных документов. В настоящее время основное внимание уделяется конструктивно-технологическим мероприятиям, направленных на увеличение термического сопротивления ограждений. Реализация повышенного термического сопротивления стеновой конструкции требует оценок термической устойчивости стены. Объектом исследования является многослойная ограждающая конструкция. Показано, что повышенное термическое сопротивление теплопроводности не всегда обеспечивает стационарность температур граней стены. В работе описывается важность следующих факторов: оптимизация температурно-влажностного режима стен; влияние включений на величину потерь теплоты; влияние двойных фасадов на тепловые потери; эффективность применения новых теплоизоляционных материалов на термическое сопротивление и энергоэффективность. В данной статье выясняется связь между активным (термическое сопротивление) и реактивным (аккумуляция) сопротивлениями ограждения на модели одномерной стенки.

Introduction

Optimization of temperature and humidity of the walls [1], impact of inclusions on the magnitude of heat loss and thermal resistance of protections [2], the influence of the double facades on heat loss [3], the effectiveness of new insulating material, including membranes fire, for thermal resistance and energy efficiency [4], cetera are studied. But from the list of particular problems, as a rule, issues of thermal stability of fences and related issues determining the accumulation of heat protections are overlooked.

Statcenko E.A., Ostrovaia A.F., Musorina T.A., Kukolev M.I., Petritchenko M.R. The elementary mathematical model of sustainable enclosing structure. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 86–91. doi: 10.5862/MCE.68.9

The accumulation capacity enclosure determines the amount of heat which is essential to maintain the desired temperature level, and the walls enclosing the room when the temperature of the external source (sink) is rising. Construction is thermally stable if the rate of temperature changes at any point of the structure does not exceed a certain limiting value. Otherwise, if the temperature of the building envelope T=T(t,x), then $\max_{x\in X}\left|\frac{\partial T}{\partial t}\right| < c_T$; or, too, the speed of temperature change is uniformly bounded on X values spatial coordinate x.

The article [1] considers thermal properties of different structural systems of ventilated facades. In [3], the authors explain the sufficient conditions necessary for the existence of free convective flow in a vertical slot channel.

Problem solutions of hydraulics non-isothermal free-convective flows of hinged ventilated facade are less represented. The number of articles on thermal transmission and hydrodynamics of ventilated air spaces of hinged ventilated facade is less then number of articles on optimization of the thermal resistance of wall fences.

The problem solution of energy saving in buildings is the subject of many studies. Calculation method of the coefficient of heat engineering design efficiency, taking into account the influence of structural elements, is proposed [5–6].

At present, the issue of the influence of the building envelope thermal protection level on the amount of thermal energy losses in the building, which is considered in the article [7].

The purpose of the article is to clarify relation between the active and reactive resistances protections on the model of one-dimensional wall

For this purpose it is necessary to complete next tasks:

1. Consider the three inequalities that express restrictions on the instantaneous temperature of the wall;

2. To analyze the properties of the Cauchy problem.

Methods

In normalized coordinates the problem is posed as follows:

$$\frac{\partial u}{\partial t} = \frac{\partial}{\partial x}\left(a(x)\frac{\partial T}{\partial x}\right), t > 0, 0 < x < 1;$$
$$\left(\frac{\partial u}{\partial x}\right)_{x=0} + h_0\big(\theta_0(t) - u(t,0)\big) = \left(\frac{\partial u}{\partial x}\right)_{x=1} + h_1\big(u(t,1) - \theta_1(t)\big) = 0, t > 0, u(t,0) = 0. \quad (1)$$

where u (t, x) – the wall temperature, x – coordinate (in fractions of a wall thickness δ), t – the dimensionless time (the number of Fourier $t := \mathfrak{F} = \frac{a_0\tau}{\delta^2}$ τ – "physical" time), $\theta_{0,1}$ – temperature of source, hot and cold, respectively (given), $h_{0,1}$ – dimensionless thermal transmission from an external source to the wall with hot and cold side (Biot number, specified), a=a(x) – reduced coefficient of thermal conductivity, $a := \frac{\lambda}{a_0 \rho c}$, given. This structure of wall is shown in Figure. 1.

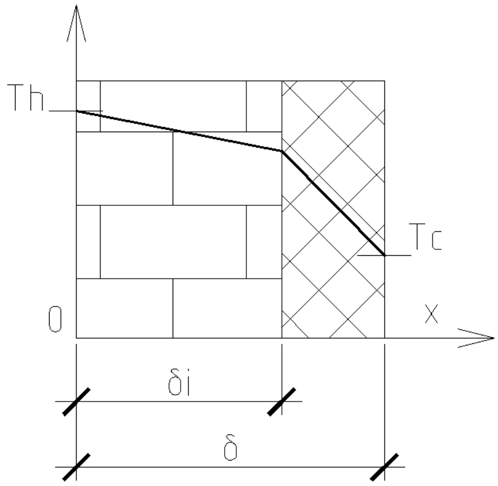

Figure. 1. The temperature distribution over the thickness of the wall

Boundary-value problem (1) is well known in the classical theory [8, 9]. Traditional methods of its solution badly work at temperatures of external sources and thermal transmission coefficients, changing in time [10–11].

It is important to note three inequalities expressing constraints on the instantaneous wall temperature:

$$\theta_1(t) \le u(t,1) < u(t,0) \le \theta_0(t) \tag{1.1}$$

and properties of the semicontinuity of limit wall temperatures as functions of Biot number. That is:

$$\theta_0(t) \ge \limsup_{h_0\to\infty} u(t,0), \theta_1 \le \liminf_{h_1\to\infty} u(t,1). \tag{1.2}$$

In order to simulate the temperature distribution, u = u (t, x) the integral identity which is obtained from the equation of the boundary-value problem (1) [8–9, 12] is used:

$$\frac{d}{dt}\int_0^1 u(t,x)dx = H_0\big(\theta_0 - u(t,0)\big) - H_1(u(t,1) - \theta_1), \tag{2}$$

$$H_0 \coloneqq a(0)h_0, H_1 \coloneqq a(1)h_1.$$

The left side of identity (2) is instantaneous speed of the average fence temperature change, that is measure of its thermal stability. On the right side of (2) the balance of the heat flux, "corrected" (authors multiply by coefficient of thermal conductivity in the limit points x = 0, x = 1) with account of the variability of the wall thermal properties along the heat flow [13, 14] is written.

Identity (2) can be converted to a differential equation for the limit temperature $u(t,0) \coloneqq \vartheta_0(t)$.

Let us assume that $u(t,x) = \vartheta_{0(t)}\exp(-m(t)x)$. Due to the expression (2) we get:

$$\frac{d}{dt}\left(\frac{\vartheta_0}{m}(1-e^{-m})\right) = H_0(\theta_0 - \vartheta_0) - H_1(\vartheta_0 e^{-m} - \theta_1) = 0, \tag{2.1}$$

where obviously ϑ_0(0)=0.

If m<<1 we obtain the following Cauchy problem for the determination ϑ_0(t):

$$\frac{d\vartheta_0}{dt} + (H_0 + H_1)\vartheta_0 = H_0\theta_0 + H_1\theta_1, \vartheta_0(0) = 0 \tag{3}$$

Statcenko E.A., Ostrovaia A.F., Musorina T.A., Kukolev M.I., Petritchenko M.R. The elementary mathematical model of sustainable enclosing structure. *Magazine of Civil Engineering*. 2016. No. 8. Pp. 86–91. doi: 10.5862/MCE.68.9

Knowing $\vartheta_0(t)$ and making use of identity $m = \frac{h_0\theta_0}{h_0+\vartheta_0}$, we can find the exponent m(t) for the next iteration. As seen in h_0<<1 assumption concerning the smallness of the m (t) is correct. Conversely, if h_0>>1, then $m(t)=\theta_0(t)$. Then the temperature approximation has the form (3.1):

$$u(t,x) = \vartheta_0(t)\exp\left(-x\theta_0(t)\right). \quad (3.1)$$

Then, $\vartheta_1(t) = \vartheta_0\exp(-\theta_0(t))$, from which we immediately obtain that the h_0>>1 temperature of hot source $\theta_0(t)$ is the logarithmic average of wall temperatures in limiting points: $\theta_0(t) = \ln\frac{\vartheta_0(t)}{\vartheta_1(t)}$.

Results are based on simple properties of the solution (4) of the Cauchy problem (3).

Results and Discussion

These properties are formulated as lemmas without evidence.

Lemma 1. The solution of the Cauchy problem (3) has the form:

$$\vartheta_0(t) = \int_0^t (H_0\theta_0 + H_1\theta_1)(\tau)\exp\left(-\int_\tau^t (H_0 + H_1)(\omega)d\omega\right)d\tau \quad (4)$$

τ, ω – integration variables.

Lemma 2. Let $t\to\infty$. Then:

$$\lim_{t\to\infty}\vartheta_0(t) = \left(\frac{H_0\theta_0 + H_1\theta_1}{H_0 + H_1}\right)_{t=\infty} \quad (4.1)$$

Otherwise, the limiting (conservative) value of the temperature of the “hot” wall face is equal to the weighted average (based on thermal transfer, "corrected" to the wall thermal diffusivity nonuniformity) temperature of the hot and cold sources.

Lemma 3. Let the "corrected" thermal transfer coefficients ($H_{i=0.1}$) and the temperature of the source ($\theta_{i=0.1}$) are constant. Then the solution (4) takes the form:

$$\vartheta_0(t) = \frac{H_0\theta_0 + H_1\theta_1}{H_1 + H_0}\left(1 - \exp(-(H_0 + H_1)t)\right) \quad (4.2)$$

Further:

$$d\,\vartheta_0/dt = (H_0\theta_0 + H_1\theta_1)\exp(-t(H_0 + H_1)) \underset{t\to\infty}{\to} +0. \quad (5)$$

The article [15–17] revealed the fact that the regulatory requirements to the level of thermal protection were lower, even though slightly, than in the requirements of the standards in 2003 (Russian Set of Rules SP 23-02-2003). Consequently, the building meets the requirements of the current Set of rules, would not provide the necessary heat protection in the present circumstances. Moreover, many construction companies do not always comply with them.

Expression (5) is also valid for slowly varying distributions $\theta_{i=0.1}$ (temperature of sources) $H_{i=0.1}$ (thermal transfer coefficients).

If the temperature of the hot wall face changes linearly, then for any finite value t> 0 of the cold source changes exponentially with time: $\theta_1(t) \approx \exp(tH_1)$. Otherwise, the rate of change of the temperature of the source and the wall faces is different: an exponential change of source temperature leads to a linear change in the wall face temperature.

In all cases, the wall storage capacity smoothes the temperature fluctuations on the wall surface. storage capacity (smoothing changes in temperature of sources – air) of the construction fence is the more, the more the value of the mentioned above thermal transfer coefficients $H_{i=0,1}$, that is, the more the thermal diffusivity coefficients $a_{i=0,1}$ of the wall faces. Thus, the implementation of the increased thermal resistance of walls through the use of heat-insulating materials with low thermal diffusivity comes into conflict with the thermal resistance of the fence. As it show in the article [18–20] thermal resistance of the ventilated facade is increased.

Conclusions

1. If H_0=0, hot wall face is insulated, the instantaneous speed of the hot wall temperature ($d\vartheta_0(t)/dt$) is determined only by the "cold" source:

$$d\vartheta_0/dt = H_1\theta_1(t)\exp(-tH_1) \tag{5.1}$$

2. The maximum rate of temperature change does not exceed the set values for all $tH_1\exp(-tH_1)$ of the cold source temperature $\theta_1(t)$:

$$d^2\vartheta_0/dt^2 = \left(\frac{d\theta_1}{dt}H_1 - H_1^2\theta_1\right)\exp(-tH_1) \tag{6}$$

3. When the final heat transfer on hot and cold faces, we have:

$$d^2\vartheta_0/dt^2 = \left(\frac{d\theta_0}{dt}H_0 + \frac{d\theta_1}{dt}H_1 - (H_0+H_1)(H_0\theta_0 + H_1\theta_1)\right)\exp(-t(H_0+H_1)) \tag{6.1}$$

4. So, when the linear (low) temperature changes reduced brink $\theta_0H_0+\theta_1H_1$ source temperature is proportional to $\exp(t(H_0+H_1))$.

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Стаценко Е.А., Островая А.Ф., Мусорина Т.А., Куколев М.И., Петриченко М.Р. Простая модель теплоустойчивой ограждающей конструкции // Инженерно-строительный журнал. 2016. № 8(68). С. 86–91.

Требования к материалам, представляемым к публикации

Материалы принимаются только через систему электронной редакции журналов СПбГПУ. Авторам необходимо зарегистрироваться в системе (http://journals.spbstu.ru/) и подать статью через нее, предварительно ознакомившись с нижеприведенными требованиями и условиями опубликования. Публикация в журнале бесплатна для авторов.

Этические нормы и авторские права

Подавая статью в журнал, автор соглашается на условия лицензионного договора, в частности, на то, что все статьи без исключения публикуются в открытом доступе на сайте журнала и в Научной электронной библиотеке России. Также автор подтверждает, что статья является оригинальной, ранее не опубликованной, содержит только проверенные и точные данные; любые данные, полученные не автором, имеют соответствующие ссылки на источник.

Тематика и язык статей

В «Инженерно-строительном журнале» публикуются оригинальные, ранее не опубликованные статьи, содержащие полученные авторами новые научные результаты, по тематике «Строительство». Принимаются статьи только на английском языке. Метаданные (аннотация, ключевые слова, список литературы) подаются на двух языках.

Структура и содержание статей

Структура статьи должна соответствовать стандарту IMRAD (Introduction, Methods, Results, and Discussion). Введение должно включать обзор литературы по теме, дискуссия (и/или заключение – Conclusions) – нумерованные выводы.

Технические требования к статьям

Статьи подаются в формате docx (MS Word 2007–2013). Файл статьи, подаваемый через электронную редакцию, должен содержать только сам текст, без названия, списка литературы, фамилий и данных авторов. Все эти поля заполняются отдельно при подаче через электронную редакцию.

Рекомендуемый объем статей: от 15000 до 30000 знаков с пробелами. Таблицы выполняются средствами Word (не рисунками) и располагаются внутри текста статьи. Иллюстрации должны быть дополнительно представлены в отдельных графических файлах (один рисунок – один файл). Допустимые форматы: JPEG, TIFF, BMP. В текстовый файл иллюстрации также должны быть включены. Все обозначения на рисунках должны быть на латинице.

Список литературы на русском языке должен быть оформлен в соответствии с ГОСТ 7.0.5-2008. Цитируемая литература приводится общим списком в конце статьи в порядке упоминания. Порядковый номер в тексте заключается в квадратные скобки. Текст статьи должен содержать ссылки на все источники из списка литературы. Также к статье прилагается список литературы на латинице, оформленный в соответствии с инструкцией по транслитерации списка литературы, размещенной на сайте издания.

Аннотация к статье

В журнал подается расширенная аннотация на двух языках: русском и английском. Аннотация должна повторять структуру статьи: актуальность, цель, методика, результаты, выводы. Аннотация должна содержать от 100 до 250 слов.

Подробные требования к статьям см. на сайте журнала:
http://www.engstroy.spbstu.ru/autors.html

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**Приглашает специалистов проектных и строительных организаций,
не имеющих базового профильного высшего образования
на курсы профессиональной переподготовки (от 500 часов)
по направлению «Строительство» по программам:**

П-01 «Промышленное и гражданское строительство»

Программа включает учебные разделы:

- *Основы строительного дела*
- *Инженерное оборудование зданий и сооружений*
- *Технология и контроль качества строительства*
- *Основы проектирования зданий и сооружений*
- *Автоматизация проектных работ с использованием AutoCAD*
- *Автоматизация сметного дела в строительстве*
- *Управление строительной организацией*
- *Управление инвестиционно-строительными проектами. Выполнение функций технического заказчика*

П-02 «Экономика и управление в строительстве»

Программа включает учебные разделы:

- *Основы строительного дела*
- *Инженерное оборудование зданий и сооружений*
- *Технология и контроль качества строительства*
- *Управление инвестиционно-строительными проектами. Выполнение функций технического заказчика и генерального подрядчика*
- *Управление строительной организацией*
- *Экономика и ценообразование в строительстве*
- *Управление строительной организацией*
- *Организация, управление и планирование в строительстве*
- *Автоматизация сметного дела в строительстве*

П-03 «Инженерные системы зданий и сооружений»

Программа включает учебные разделы:

- *Основы механики жидкости и газа*
- *Инженерное оборудование зданий и сооружений*
- *Проектирование, монтаж и эксплуатация систем вентиляции и кондиционирования*
- *Проектирование, монтаж и эксплуатация систем отопления и теплоснабжения*
- *Проектирование, монтаж и эксплуатация систем водоснабжения и водоотведения*
- *Автоматизация проектных работ с использованием AutoCAD*
- *Электроснабжение и электрооборудование объектов*

П-04 «Проектирование и конструирование зданий и сооружений»

Программа включает учебные разделы:

- *Основы сопротивления материалов и механики стержневых систем*
- *Проектирование и расчет оснований и фундаментов зданий и сооружений*
- *Проектирование и расчет железобетонных конструкций*
- *Проектирование и расчет металлических конструкций*
- *Проектирование зданий и сооружений с использованием AutoCAD*
- *Расчет строительных конструкций с использованием SCAD Office*

П-05 «Контроль качества строительства»

Программа включает учебные разделы:

- *Основы строительного дела*
- *Инженерное оборудование зданий и сооружений*
- *Технология и контроль качества строительства*
- *Проектирование и расчет железобетонных конструкций*
- *Проектирование и расчет металлических конструкций*
- *Обследование строительных конструкций зданий и сооружений*
- *Выполнение функций технического заказчика и генерального подрядчика*

По окончании курса слушателю выдается диплом о профессиональной переподготовке установленного образца, дающий право на ведение профессиональной деятельности